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A REVIEW OF SPECTROGRAPHIC ANALYSIS OF SOME METALS AND ALLOYS.

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The layman, in investigating the possibilities of employing spectrographic methods of chemical analysis of materials has found that much of the literature written on the subject expounds the highly technical features in which he is not primarily interested. In describing results which may be obtained by the use of this method of analysis the readers knowledge of the basic theory is frequently assumed. The authors have attempted in the following article to present a comprehensive picture of the factors involved in routine spectrographic chemical analysis, discussing only such elementary theory and technical considerations as are necessary for clarification. The article points out that the use of the

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spectrograph for analysis within much closer limits than are specified by Navy specifications indicates that high credibility is attributed to the results obtained where it is feasible to employ this method of analysis. The article emphasizes that the often expressed opinion that spectrographic methods are applicable only to the determination of small amounts or traces of impurities is not true in the light of modern development of spectrographic procedures. The modern spectrographic analysis of steel or aluminum alloys for example, produces quantitative analyses of major metallic constituents as well as impurities with exactitude within a small fraction of elapsed time and of expense required for conventional wet methods. The authors discuss laboratory organization, various installations and costs and present a number of specific procedures in actual use. In addition, a forecast of what may be expected in further development, in the near future, is set forth.

CHAPTER I.

Introduction.

Since the advent of the present war and the transition from peace time to military production there have arisen an ever increasing demand for speed and a growing tendency to discard procedures of inspection unless the workability of these procedures is such that no slowing down of production results from their application. At the same time, the fact of the immensity of the job to be done has had and is having its effect on quality. The need for controls to assure that materials will ultimately be suitable for the purposes intended has never been more imminent. This is particularly true when such factors as lower quality refractories; lower quality basic raw materials, resulting from the need to use all available sources; the employment of plants and equipment perhaps never intended for such production and the necessity to utilize personnel lacking in experience are considered. With the recognition of the foregoing considerations and the knowledge of what has been and can be done with spectrography to speed up, simplify, and reduce the cost of qualitative and quan-

titative analyses of certain metals and alloys, this review is prepared. It is hoped that this paper will have the effect of extending the application of this useful inspection procedure, by simple statements of its uses and limitations, by discussion of the savings in time and money attendant on its use and finally by citing specific procedures.

Specific procedures have been developed in actual practice at the Industrial Test Laboratory at the Philadelphia Navy Yard, and have been successfully used over a long period to speed the reporting of many thousands of analyses and to expedite the release of countless tons of materials for Naval use.

For the purpose of discussion, chemical analysis will be considered as a step in the inspection of certain materials, principally metals, to determine the conformity of their chemical compositions with the requirements of purchase specifications. Such an inspection procedure must be mechanical, routine, objective, simple and capable of application in a manner quite analogous to the use of gauges to select rods whose diameters are between specified limits or the Rockwell Hardness Tester to select articles within a specified range of hardness.

The analogy between chemical analysis for routine control and the use of "go, not-go" gauges may be expanded even further. Neither the inspector with his gauge nor the chemical technician should be permitted to exercise much judgment in interpretation of results but should perform predetermined operations and report his findings thereon. The merits of such procedure briefly are: rapidity, low cost, and employment of comparatively semi-skilled operators. Looking upon chemical analysis as a routine procedure of inspection simply to determine composition conformity within certain limits, any development which makes that procedure more mechanical, objective and consisting of simple component operations enhances its mass production characteristics.

In the light of the foregoing, it is important to disassociate ideas hitherto frequently deemed inseparable in order that the proper view of the relationship between chemical analysis and chemical methods of chemical analysis be attained.

To be workably expandable to meet present exigencies, the means of obtaining a routine chemical analysis must not be an

art requiring skilled scientists, every step of which involves judgment, acumen, and decision on the part of the operator, but rather a predetermined "belt line" procedure that is mechanical and objective and consists of simple mechanical components so controlled in its conception that the results will be usably accurate on a statistical basis for a great many analyses, but may sacrifice extreme accuracy and precision of an individual analysis. For example, in considering the control of the aluminum base alloy, duralumin, any method would be suitable, whether it be chemical or physical, that will determine the content of the principal alloying constituents of copper, manganese and magnesium and the traces or impurity elements with an accuracy and precision sufficient to determine conformity with the specification requirements.

Though chemical methods are direct (in a chemical sense) and simple in theory, they often require a high degree of technical skill in their execution, and are rarely capable of organization into a few simple component operations. There is little similarity between methods of analysis due to the difficulties usually encountered in chemical separation. A chemical method is essentially an individualistic procedure. Simplification tending toward greater speed and lower cost is primarily an arrangement to perform many operations simultaneously by many operators. It follows that real improvement must involve change in concept. This change in concept is a change from chemical methods of chemical analysis to physical methods of chemical analysis. The most outstanding example of this shift in methods has been the introduction of the spectrograph and its allied equipment into the field of chemical analysis.

Though spectrographic methods of chemical analysis are physical, once basic standards have been established, the bases of spectrographic analyses are specimens of known chemical composition which have been carefully analyzed and repeatedly checked by conventional analytical methods. The analysis of these specimens with the spectrograph provides the basis for establishing spectrographic standards or limits. After these standards have been established and technique of methods worked out, spectrographic analysis as principally discussed herein, becomes merely empirical interpolation between two points. The total effect can hardly be

considered less than revolutionary. For a mass of methods filling many volumes, many of which require a high degree of skill and judgment, the spectrograph, and allied equipment substitute one basic method which naturally breaks down into the following six simple unit operations:

1. Preparation of specimens.
2. Excitation.
3. Exposure.
4. Development or photographic processing.
5. Densitometry.
6. Determination of element percentage.

It is noteworthy that whatever material within the scope of the spectrograph is analyzed for any one of its constituents, the basic procedure is as given above. The simplification is, of course, concomitant with emphasis upon and necessity of instrumental control, as opposed to the methods employed by the analytical chemist, using conventional wet chemical methods.

The chemist, after his tables and hoods are available, as a rule, requires no instrumentation more complex than a good balance, glass-ware which though frequently unusual in appearance is simple in a functional sense, filter paper, reagents and a source of heat. An electrolytic outfit may be desirable but is by no means essential. These then are simple tools and it appears natural that a good chemical analyst must necessarily be a rather skillful and ingenious scientist to obtain good results. On the other hand, the instrumentation of modern spectrographic methods of chemical analysis, is complex and elaborately involved. The difference in spectrographic methods becomes a matter of minor adjustments in the instrumental control which, though minor, are nevertheless very important. As opposed to the duties of the analytical chemist the spectrographic operator need only insert a specimen into a simple grinder, then into the jaws of a clamp, push a few buttons, make occasional adjustments with a crank handle, process the photographic plate and watch timers. In the more elaborate installations, even some of these operations are mechanical so that the operator is eventually a button pusher. With all its elaborate instrumentality, the spectrograph still cannot

be classed as a fearsome robot. Consider the instrumentality of the modern radio receiver which adorns your home and incorporates automatic tuning and perhaps automatic record changing. Anyone can get a wide variety of stations, or play a complete symphony merely by pushing a few buttons. The problem of maintenance of a good set is trivial. If it does break down, competent specialists make the repairs. Certainly, the mastery of the instrumentation of a well designed spectrographic installation is hardly more difficult than a radio receiver from the technicians or operators' point of view. Of course, the problem of devising new spectrographic methods, procedures, or instruments, or improving existing ones is another consideration, just as the improvement or research in the field of radio is quite a different matter from pushing a button and adjusting a volume control knob.

Spectrographic Analysis.

Spectrographic analysis is defined as the technique of chemical analysis characterized by the use of the spectrograph and allied equipment. The terms "spectrochemical analysis" and "chemical spectrography" are used synonymously in the literature. The operations of the basic method of spectrographic analysis will be briefed here and discussed technically later.

1. Preparation of Specimens.

The specimens, usually solid pieces of metal, are ground on an emery belt free, of contamination, so that a clean surface is exposed. Two specimens may be used each approximately ¼ inch in diameter by 1 inch long with one end ground flat, conical, or spherical depending upon technique to be used in excitation.

2. Excitation.

The specimens are then clamped in the jaws of an electrode holder or fixture. Specimens may serve as one or both of the electrodes. If only one specimen is used, a graphite rod properly ground at one end is usually used as the counter electrode. The gap between the electrodes, the distance from and elevation relative to the slit of the spectrograph are properly adjusted. An electric potential is then applied to the electrodes. Various arcs

or sparks may be used depending on the nature of the material and method employed. Such arcs and sparks are: d-c low voltage, high amperage arc (220 v., 5-25 amp.); a-c high voltage arc (2200/4400 v., 2-8 amp.); a-c high voltage spark (17000-47000 v. 20-120 milli-amp.) or other variations of the arc or spark. The light is passed through a narrow slit into the spectrograph.

3. Exposure.

The spectrograph has a camera device, containing a photographic plate. The plate is exposed for a definite time to the light passing through the spectrograph. Exposure is usually in the range of 10 seconds to 4 minutes, depending on the material to be analyzed. Lenses for focusing, prisms or gratings for refraction and/or dispersion, and, diaphragms for optical characteristics are used.

4. Development.

The exposed plate is developed, fixed, washed and dried in a manner qualitatively similar to the processing of any other exposed photographic plate. The spectrum, as it appears on the finished plate, consists of a number of vertical lines, in a horizontal row. The blackness and pattern or distribution of these lines are characteristic of the material in the specimen. The interpretation of these factors readily becomes a routine means of determining chemical composition.

5. Densitometry.

The plate is then placed in a densitometer or instrument for measuring blackness, and the blackness or per cent of light transmitted through several selected lines is measured.

6. Determination of Percentage.

Using the measurements obtained in the densitometer in conjunction with "working curves" the percentage of each element is read directly. The total elapsed time for one sample may be from 5-20 minutes. The total elapsed time for 10 samples may be from 20-60 minutes. The analysis may involve 1 to more than 10 constituents per sample.

CHAPTER II.

SPECTROGRAPHY.

Spectroscopy as a field of experimental and theoretical research has contributed much to our knowledge concerning the physical nature of things—knowledge not only of our own earth but of the sun, of interstellar space and of the distant stars. It may rightly be said that spectroscopy had its beginning in the year 1666 with the discovery by Sir Isaac Newton that different colored rays of light when allowed to pass through a prism were refracted or deviated from the original path, through different angles. Sunlight confined to a small pencil or cone of rays by means of a hole in a diaphragm and allowed to pass through a prism was spread out into a beautiful rainbow band or "spectrum." Sir Isaac Newton's description of this phenomena is quoted as follows:

"And so the true cause of the length of that Image was detected to be no other, than that Light is not similar or Homogenial, but consists of Difform Rays, some of which are more Refrangible than others."—Isaac Newton, 1666.

Although it was known to the Ancients that clear crystals when placed in direct sunlight gave rise to spectral arrays, it remained for Newton to show that the colors did not originate in the crystal but were in fact the ingredients of sunlight. With a lens in the optical path, the band of colors falling upon a screen became a series of colored images of the hole in the diaphragm. This band Newton called a "spectrum".

It is interesting to perform a similar experiment using, instead of the round hole in a diaphragm, a rectangular slit not over one ten-thousandth of an inch wide and instead of Newton's glass, a prism of optically clear quartz and finally instead of sunlight, the light emitted by a piece of solid material which has been heated to incandescence. The array of colors produced by the light of the glowing bar passing first through the slit and then through the prism, when properly focused on a screen by lenses, will resemble the Newtonian spectrum of sunlight. Altering or changing entirely the chemical composition of the incandescent material will not change this resemblance. In other words, no difference in appearance of such spectra can be ascribed to the chemical nature

of the incandescent material. If the "spectrum" is focused on a photographic plate instead of the screen mentioned above, upon development of the plate, a black band of varying intensity will be produced. This change from color to the varying black band is the familiar recording of black and white photography. The band on the photographic plate, however, will be found to be considerably longer than the band of color observed on the screen by the eye. This is due to the wave-like structure of light, and to the important property of wave-like phenomena called wave length. Within certain narrow limits the eye perceives differences in wave lengths of light as differences in color. Scientific measurements have determined that as we proceed through the familiar colors of violet, indigo, blue, green, yellow, orange and red there is a progressive increase in the wave length. However, this wave-like disturbance known as light extends far beyond the range visable to the eye. Light or radiation of wave lengths shorter than violet is designated as being in the ultra violet region, while light of wave length longer than red is designated as being in the infra-red region. The photographic plate being sensitive to light of wave lengths which the eye cannot perceive as color, records a band of varying blackness which is longer than the band of varying color perceived by the eye. It was stated above that there are no variations in the appearance of the spectra that can be attributed to the chemical nature of a glowing or incandescent solid bar or body. However, increasing the temperature from dull red heat, for example, through a lighter red, orange and yellow to a dazzling white is accompanied by a marked overall increase in the intensity of the spectra with a relative shift of intensity towards the short wave length or ultra-violet region.

The spectrum of an incandescent gas presents quite a different picture. While the light from an incandescent gas may appear to the naked eye to be similar to that emitted by an incandescent solid, the spectra are entirely different. If the foregoing experiment is repeated, focusing on the screen the light of an incandescent gas instead of light emitted from an incandescent solid, a rainbow or Newtonian spectrum does not result. Instead, a number of colored bright lines (actually images of the slit) appear irregularly spaced and of varying intensities throughout

the spectrum. The distribution and pattern of these lines and their relative intensities are dependent upon the chemical nature of the gas, and only in a relatively minor way upon its temperature. If this spectrum is focused on a photographic plate and the plate is developed, there will result a number of black lines (slit images) in a horizontal band extending indefinitely into the ultra violet and infra red regions. The spectrum of a single element may contain a few or many lines of varying wave lengths and intensities appearing in different positions in the spectrum. Reference to published spectrum tables which give the wave lengths of the emitted radiation characteristic of various chemical elements provides the basis for qualitative analysis of the material. To return to the spectrum produced by light emitted by the glowing solid bar or body, assuming that the emitted light has components of wave lengths, for example of 1000 units and of 3000 units, we expect to find and do find components of any wave length between 1000 and 3000 units. The intensity of any such component depends on the absolute temperature only, and not at all on the chemical composition of the bar or body. As indicated by the type of spectra, above described, produced by an incandescent gas, the light from that gas is not continuous with respect to wave length. On the contrary, the emitted light or radiation is composed of a definite number of waves of definite wave lengths. The intensity distribution among the wave lengths present is not uniform. Actually the wave lengths present are characteristic of the chemical elements present in the gas and a mixture of the elements will radiate the wave lengths characteristic of all the chemical elements present.

In view of the foregoing, the spectrum of a chemical element can be defined as that set of wave lengths present in the radiation emitted by that element in the incandescent gaseous state.

There are four basic properties associated with wave-like phenomena which are of interest in spectrographic chemical analysis:

1. The speed or velocity of wave disturbance or propagation.
2. The wave length.
3. The frequency.
4. The intensity or amplitude.

Of these properties, wave length and intensity are most important. Generally speaking, the problem of spectrographic analysis resolves into the determination of the intensity of some selected wave length of light.

Considering the spectrum of an element as a whole, it may be said that the intensity of that spectrum increases with the temperature of the gas and with the concentration of that particular element in the emitting mixture. The spectra considered above should properly be called emission spectra. It can be demonstrated that white light or similar radiation transmitted through some liquids suffers selective absorption. This is apparent when the absorption range is in the region of light to which the eye is sensitive. White light transmitted through red ink comes out red; all but the red portion of the white light being absorbed by the ink. The phenomenon of color, as distinguished by the eye, depends on the frequency of the radiation striking the eye. Water white liquids, for example, chloroform, or benzene, selectively absorb radiation of frequencies either too high or too low (ultra-violet or infra-red light) to be perceived by the eye at all, let alone as definite colors. The study and analysis of the selective absorption or reflection of materials is called spectro-photometry and deals with absorption spectra, which depend on the molecular structure of materials as opposed to the correlation of atomic structure to elemental and emission spectra. Emission spectra are sometimes called atomic spectra for this reason. Absorption spectra and spectrophotometry are mentioned only in passing. This paper is restricted to a discussion of spectrographic chemical analysis which employs emission or atomic spectra. For brevity, the term spectrography is used to mean chemical analysis using the spectrograph.

That property of an instrument, usually optical, which breaks up or analyzes a beam of light into its component wave lengths is called dispersion. The principal instrument used for this purpose is the spectrograph.

Application to Chemical Analysis.

To analyze a solid metallic body, the material must first be brought into the form of an incandescent gas. This is usually

accomplished by making the material to be analyzed the electrodes of an electric arc or spark gap. If the electric excitation is intense enough, that is, if the arc is of sufficient amperage or the spark of sufficient voltage, capacity, etc., material from these electrodes will enter the arc or spark gap and become an incandescent gas. The gas will emit radiation which is not continuous with respect to wave length but which will have only those wave lengths present that are characteristic of the chemical elements in the specimen. The radiation or light is then passed through a spectrograph and its spectrum recorded on a photographic plate which is the means of determining the wave lengths present in the radiation. Identification of the vertical lines present provides a qualitative analysis of the material in the arc gap. Of first importance in spectrography is to make the material in the arc or spark gap representative of the material present in the electrode, for it is the analysis of the electrodes that is desired. Thus far only qualitative analysis has been discussed. The quantitative aspect of chemical analysis requires a second consideration.

The gases in the electric arc must be not merely qualitatively representative of the electrodes but quantitatively as well. It is therefore, of the highest importance to insure a stable excitation source, i.e., one that will always produce similar electric arcs from similar electrodes. Once that has been achieved, it is a comparatively simple matter to correlate the intensity of the spectrum of an element in an analytic arc, or as is usually done, the intensity of some definite wave lengths in the spectrum of that element, with the percentage, or concentration of that element in the arc which is in turn correlated with the concentration or percentage of that element in the electrode under analysis.

Thus the entire problem of spectrographic analysis is reduced to the determination of (1) the presence of radiation of a definite wave length and (2) the intensity or relative intensity of the radiation of that wave length. Thus one qualitative and one quantitative determination are necessary for the analysis of any element in any kind of material within the scope of spectrography.

As was stated in the previous section, the intensity of the atomic (emission) spectrum as a whole, of an element depends on various factors such as temperature and the number of atoms of the

element per unit volume of the radiating gas. There are also quantum theoretical considerations such as transition probabilities and energy differences between initial and final levels which must be taken into account in the design of equipment and the development of methods. However, there is ample development in the art and experience in the application of methods to calm the disturbing thoughts that these ominous sounding terms may engender.

While it is customary to use an electric arc or spark to convert the material into an incandescent gas, there are other means. For example, the Lundegardh method dissolves the material and then aspirates it into an oxy-acetylene flame. Such a procedure has some advantages in some special instances.

Theoretically, there is no reason why all elements cannot be determined in whatever percentages they are present. However, since we are limited to commercial instruments, and by such factors as speed, and accuracy, routine spectrographic analysis is confined to metallic elements. Such elements as carbon, sulphur, chlorine, bromine, iodine, and the gases such as oxygen, nitrogen, hydrogen, the rare gases and perhaps selenium are excluded from the elements, which can be practicably analyzed by this method at this time. A mixture of gases, or essentially an impure gas, can be enclosed in a discharge tube at a proper pressure and excited under proper electrical conditions, and its spectrum thus obtained in an otherwise normal manner. On the other hand, oxygen or hydrogen in steel cannot be excited in any manner that is practically feasible. Other elements, such as sulphur and chlorine, have characteristic spectra of such a nature that absorption in air and quartz often becomes a limiting factor. The recording of the spectra of these elements requires special apparatus such as the vacuum spectrograph, with optics made of selected minerals difficult to obtain. These elements present difficulties which at least for the present are too great for any practical consideration.

Considerations of accuracy, in large measure involved in the use of the photographic emulsion, limit the concentration of the element sought to less than 10 per cent, in general. The lower

limit of detection and estimation is at present far beyond any practical needs.

It may be stated that spectrographic analysis is limited to:

(1) *a.* estimation of elements and
b. metallic elements.

(2) Amounts from 0.001 per cent to 10 per cent as a general rule. Exceptions may in certain instances bring the lower limit down to 0.000001 per cent and the upper limit up to 20 per cent.

At present, routine quantitative analyses may be applied to the determination of both major and minor constituents of basic alloys of ferrous and non-ferrous materials, with the exception in some cases of the determination of the major constituents of highly alloyed metals, such as brass or bronze.

CHAPTER III.

Merits of Spectrography.

The merits of spectrographic methods of routine chemical analysis are, generally speaking, speed, low cost, adaptability to the varying needs of inspection systems where immediacy is paramount; the elimination, largely, of the human equation; the production of permanent records; ease of checking its own accuracy; its mass production control characteristics and certainly not least, cleanliness. The Spectrographic Section of the Industrial Test Laboratory at the Philadelphia Navy Yard, where hundreds of analyses are performed daily on various types of materials, might well be the carefully appointed suite of display rooms of a fine instrument manufacturer. Even the orderly and efficient management of the adjacent conventional chemical Laboratory cannot hope to maintain comparative working conditions.

The experience and records of the Yard's spectrographic laboratory as well as those of the chemical laboratory, together with the writers' knowledge of other installations will be drawn upon to discuss the merits of routine spectrographic analysis of materials.

These methods are composed essentially of short time unit operations. The time shown below in each case is average or on the liberal side:

In the analysis of steels the specimens are generally received in the form of rods or pencils about 3/16 inch diameter by 1 inch long. Each sample consists of two pencils. The time breakdown for complete analysis is as follows:

1. *Preparation of sample.* Consists of placing the sample in a special fixture and grinding one end to a cone of predetermined angle. Time required (.5) one-half minute. Little time is saved by grouping many samples for preparation.

2. *Pre-excitation.* Before exposure of the plate, power is applied to the electrodes and the "gap" pre-excited usually for about 10 seconds to allow stabilization. This time is included in the time shown under "exposure".

3. *Exposure.* It is very often desired to determine the percentage of several elements in a sample, the concentrations of which vary greatly. The spectra of some of these elements may contain lines of high density under a given time of exposure while other elements may require considerably longer periods of exposure to produce lines of sufficient density. Therefore, in many cases, two exposures are made of a single sample, one producing light spectra and the other producing dark spectra. It is also frequently desirable to obtain a wider range of wave lengths than is possible within the length of the plate used and again a second exposure is necessary. These additional exposures require instrument adjustments and movement of the plate holder to a second position. Therefore, to account for these conditions exposure time used here is that necessary for two exposures and can liberally be considered as 1.5 to 2.0 minutes.

4. *Photographic processing.* The time required per plate is as follows:

To develop	45 seconds.
To rinse and fix	1 minute, 15 seconds.
To wash	1 minute, 30 seconds.
To dry	1 minute, 30 seconds.
Total elapsed time	5 minutes per plate.

Since the plate is processed as a whole, there is a saving in time (per sample) if spectra of several samples are recorded on one

plate. It is routine practice at the Industrial Test Laboratory to record as many as 24 spectra (12 samples or more) on one plate. Thus if a single spectrum for each of 24 samples is recorded on one plate the elapsed time per sample is less than 15 seconds; for two spectra for each of 12 samples the elapsed time per sample about 30 seconds and so on.

5. *Densitometry.* An experienced operator can align selected spectral lines on the densitometer and operate his recording potentiometer (repeating for check if necessary) at the rate of four lines per minute. If six elements are to be determined per sample the time per sample is thus 15 seconds per element or 1½ minutes per sample.

6. *Determination of Percentage.* Consists of translating the potentiometer recordings by means of calibration curves for each element into percentages of the elements directly. The time per sample of six elements averages 1½ minutes. Where a typical sample is repeated the operator becomes so familiar with values that he is able to determine from the potentiometer recording directly without reference to the curves whether the percentage is within specification limits. In fact, when many analyses are repeated on material of the same specification, it can be readily determined by scanning the plate with the naked eye in comparison with known standard limits that the density of a selected line is within these limits.

From the foregoing, one-two spectra—six element sample requires 9.5 minutes for the six operations while 12 (2 spectra) samples on one plate require 59.0 minutes or less than 5 minutes per sample.

At this point it is of interest to note that in a large middle-western plant the analysis of the product of 35 furnaces is "controlled" by one spectrograph with allied development, drying and densitometer equipment performing some 2600 individual element analyses in 24 hours using three shifts of four people each.

The process of analysis comprises: (*a*) the casting of small pencil specimens of the molten alloy and dispatching them by pneumatic tube to the laboratory, (*b*) grinding and preparation

of the specimens, (*c*) exciting the specimens as electrodes in a 40,000 volt controlled and interrupted spark gap, (*d*) passing the light through a Littrow type quarts spectrograph and recording its spectrum on a photographic plate, (*e*) the plate is developed, dried and passed on to the densitometry room, (*f*) here the plate is placed in a microphotometer utilizing photo cells to compare the density (blackness) of a selected spectral line for a given element with the density of an adjacent known line of the basic material, (*g*) through the medium of the established "blackness-versus-intensity" relationship the readings are converted to percentage content by means of a transposing apparatus which is a sort of slide rule with scales drawn from readings on standard samples of which the composition is accurately known. This phase produces the analysis of a sample for five elements with duplicate records written in 90 seconds. Standard samples are read several times per day to check accuracy of the scales and provisions are made for the minor adjustments occasionally needed.

Samples are "shot" by the foundry clerks (some 2000 feet away) to the laboratory by means of the pneumatic tube system. Results are returned in the same manner. If required, the results of a single sample can be reported within 7 minutes from the time it is received in the laboratory. Ordinarily the company employs the laboratory to ascertain that additions to the furnaces do not produce changes in composition which are outside the specification limits. For this purpose, an overall time of 20 minutes from sampling the melt to receipt by the foundry clerk of the analysis is satisfactory. The laboratory maintains delivery time of analyses within 10 to 15 minutes. Gas to hold temperature of a furnace costs about $3.50 per minute. With many heats poured per day, this cost is an incentive not to delay reporting of analyses. The cost for analysis of 5 elements was reported to the authors to average $0.13.

For a typical aluminum alloy analyzed at the Philadelphia Yard for manganese, magnesium, copper, zinc, iron, silicon and chromium, the time breakdown for one sample is as follows:

1. Preparation	30 seconds.
2. Exposure	35 seconds.
3. Photographic Processing (depending on the type developer used)	5 to 10 minutes.
4. Analysis	2 minutes.
Total elapsed time—1 sample	8 to 13 minutes.
Total elapsed time—12 grouped samples	40 to 45 minutes.
Time per sample of 12 group	3⅓ to 3¾ minutes.

The Industrial Test Laboratory of the Philadelphia Navy Yard has many times completed the analysis of 300 aluminum samples in a 16-hour day. It has been the experience of this laboratory that the skill or zeal of the operator has little effect on time per operation. Pre-excitation, exposure and development are timed operations controlled by a stop watch or an electric timer. Some densitometers have an automatic plate "traverse" which eliminates the normal operation of shifting the plate. As soon as the operators become familiar with the steps involved and no time is lost between operations, routine production analysis proceeds at a uniform rate.

Because of the short time involved in each of the operations careful thought must be given to arrangement to obviate loss of time between these operations. The laboratory layout should be compact and the place of each successive operation directly accessible from the location of the preceding operation. Time of transit from room to room or in making unnecessary steps within a room may exceed the time of the operations themselves. The operations are adaptable, however, to continuous flow without appreciable lost motion when good arrangement is provided.

Costs.

Without regard to the tremendous time saving over any other method of chemical analysis which itself is of inestimable value in expediting the release of material for fabrication, spectrographic methods are low cost methods. This statement is predicated on the assumption that the work load justifies the use of spectrographic methods. A work load of 10 samples per day would

show a comparatively high cost per sample whereas a work load of 100 samples or more per day will show a low cost per sample. Labor costs based on 100 samples per day and on a cost of $1.00 per hour for labor:

Labor.

1 sample—10 man minutes	$0.163
1 sample (Basis of 12/plate) 4 man minutes per sample	0.067

On the basis of six determinations per sample the labor costs per determination are:

For a single sample	$0.027
For 12 samples on one plate	0.011

If there is no particular urgency in reporting the analysis of each sample or group of samples as they are completed, and many samples of a certain specification can be run continuously, costs lower than those given above can be maintained. For example, labor costs on aluminum samples involving 7 determinations, with reports mailed at the close of each working day have been analyzed and show a labor cost plus general supervision of $0.08 per sample or $0.011 per determination. These costs include some addition of time for preparation of samples which are obtained by the Inspectors at places of manufacture and vary in size and shape and must be finally prepared in the laboratory. Labor costs per specimen run from 6 cents to 15 cents in special cases and will average about 10 cents.

Consumable Materials.

Plates. Photographic plates suitable for spectrographic analysis cost about 13 cents each. From 1 to 24 spectra may be recorded on a plate representing from 1 to 24 specimens. Each spectrum may be suitable for the determination of 1 to 6 or even more elements. The cost per sample or for determination of an element is, therefore, variable, but will run liberally at 2 cents per sample, as an average.

Chemicals.

The cost of photographic chemicals is also low. Under the conditions of average work loads this cost runs about $6.00 per

week for developer and fixing solutions at the Philadelphia Navy Yard.

Miscellaneous.

Graphite electrodes, as stated, may be used as counter electrodes for excitation of some specimens. The cost of graphite electrodes suitable for routine work, where used, is less than 2 cents per sample. Graphite electrodes of special purity are occasionally required and cost about 10 cents each. Their use is so occasional in routine work that their cost spread over any average determination is negligible.

Power Cost.

The average exposure time is less than 1 minute. The cost of power per exposure may vary from perhaps .05 cents to 1.5 cents in special cases. An average power cost per specimen might run 1/10th cent. In any case, power cost for excitation is in the category of room lighting, small grinder motor power, operation of electric timers and small motors used for rocking the photographic developing trays and for operation of the densitometer. Power cost is low.

Depreciation.

There is practically no depreciation in spectrographic instruments in the sense that depreciation applies to rotating machinery. A spectrograph or a densitometer properly handled will last indefinitely. Excitation equipment capable of reproducing stable uniform arcs or sparks is not only used for short intervals but at a low percentage of its capacity. Equipment such as transformers, inductors, resistors and condensers are long lived under these conditions. Electrode holders and clamps if properly designed should last many years. Well built equipment is " over designed " to withstand routine abuse. An installation for over a thousand analyses per week should pay for itself at the rate of about 50 per cent per annum. Thus the amortization period is short and obsolescence, even considering the present rapid growth and development in the art, is hardly a factor to be considered. As long as an installation produces results and returns which are satisfactory to management, there is little point to installing new or additional equipment. Careful inspection and daily maintenance of

small details and reasonable care in handling will produce startlingly low maintenance costs.

Installation Investment.

Various instruments are available to suit the demands of the individual laboratory. Selection will depend upon the assignment to be fulfilled. Utmost speed and precision involves more elaborate instrumentation with higher initial costs. A range of prices given in round figures for various instruments and equipment follows:

Light Source or Excitation.

d-c arc (220 volts) Rheostats, meters, etc.	$ 150.00
High voltage spark equipment (simple unit)	200.00
Various commercial "arc" and spark units are available. The average cost is about	2000.00
Special controlled arc circuit combined with a-c arc up to	9000.00

Spectrographs.

Large Littrow suitable for steel spectra as well as simple spectra range from	3000 to 6000.00
Medium Quartz for light alloys of simple spectra	2500.00
Grating type suitable for any complex spectra	5500.00

Densitometers.

Various types are available, recording and non-recording ranging in price from	200.00 to 5000.00

Miscellaneous.

Microscope for measuring spectra	500.00
Dark room equipment (without plumbing)	300.00
Pellet press (for special specimens)	200.00
Specimens grinding equipment and jigs	200.00

In addition there are necessary: viewing boxes, hand magnifiers and miscellaneous devices. It is estimated that a completely equipped laboratory suitable for accurate, fast routine steel analysis to include even complex steels can be installed in available space at an investment cost of about $25,000.00.

Personnel.

There are consultants in departments of various Universities who are connected with industrial research and in technical institutions who have been responsible for the development of commercial equipment and methods and who have supervised selection of equipment and instruments and their installation in outstandingly successful laboratories. If an experienced engineer or laboratory director is not available, the services of these consultants may be had to survey the job, make the layout, select and supervise installation of equipment, make check runs, set up standards, train operators and thereafter serve as consulting supervisors. No installation should be considered without competent technical supervision the requirements of which will be discussed under laboratory organization. However, when methods and techniques have been developed they can be performed by semi-skilled operators. Intelligent boys or girls with high school education will be found entirely satisfactory for the various routine operations. The training of such operators will be found roughly comparable to the training of young people in the simple procedures of running carbon, manganese or phosphorus and sulphur in carbon steels by conventional wet methods of chemical analysis.

Reliability of Results.

It is not the purpose or intent of the authors that this paper shall, at this point, become a discussion of the theory of probabilities or a mathematical treatise striving for the establishment of criteria for the evaluation of the results of routine analyses whether determined by conventional methods of wet analysis or by the spectrograph. Suffice it to say that standards of sufficient exactitude are available or may readily be produced by carefully repeated chemical analysis to establish the limits necessary for practical determinations of the conformity of the materials under analysis with the specification requirements. Carefully repeated analyses of such standards, made by spectrographic methods do produce spectrographic standards sufficiently accurate for purposes of checking accuracy of methods and procedures. It is believed that the tables which follow in this section illustrate the

reliability of spectrographic analyses sufficiently to estabish high credibiity for the results obtained by this method, within the scope of its application. Unless otherwise stated, these data have been obtained from the records of the Industrial Test Laboratory at the Philadelphia Navy Yard. In explanation of the terminology employed in Tables I to VI, a short discussion of the terms is given below.

Tests for Reproducibility or Precision.

Table I.

Aluminum Alloy	Type 24S		
Element Analyzed	Magnesium		
Number of Analyses Per Sample	50		
Sample Number	226	227	228
Magnesium Present	1.21%	1.48%	1.60%
Spectrographic Analyses:			
High	1.38%	1.58%	1.71%
Low	1.09%	1.34%	1.46%
Mean	1.21%	1.48%	1.60%
Standard Deviation	0.059	0.054	0.043
Tolerance	0.040	0.036	0.029
Rejects	None	None	None
Relative Tolerance	3.3%	2.4%	1.8%

Table II.

Aluminum Alloy	Type 3S			
Element Analyzed	Manganese			
Number of Analyses per Sample	50			
Sample Number	249	250	251	32830
Manganese Present	0.90%	1.09%	1.27%	1.10%
Spectrographic Analyses:				
High	0.97%	1.18%	1.39%	1.12%
Low	0.83%	1.00%	1.17%	1.03%
Mean	0.90%	1.09%	1.27%	1.08%
Standard Deviation	0.033	0.041	0.048	0.031
Tolerance	0.022	0.028	0.032	0.020
Rejects	None	None	None	None
Relative Tolerance	2.5%	2.6%	2.5%	1.9%

TABLE III.

Aluminum Alloy	Type 24S		
Element Analyzed	Manganese		
Number of Analyses per Sample	50		
Sample Number	226	227	228
Manganese Present	0.38%	0.58%	0.84%
Spectrographic Analyses:			
High	0.41%	0.62%	0.90%
Low	0.35%	0.54%	0.80%
Mean	0.38%	0.58%	0.84%
Standard Deviation	0.016	0.021	0.033
Tolerance	0.010	0.014	0.022
Rejects	None	None	None
Relative Tolerance	2.5%	2.5%	2.6%

TABLE IV.

Aluminum Alloy	Type 43			
Element Analyzed	Silicon			
Number of Analyses per Sample	50			
Sample Number	93	94	95	96
Silicon Present	3.50%	4.55%	5.67%	6.49%
Spectrographic Analyses:				
High	3.65%	4.72%	5.95%	6.70%
Low	3.35%	4.35%	5.40%	6.22%
Mean	3.50%	4.55%	5.61%	6.45%
Standard Deviation	0.07	0.10	0.16	0.13
Tolerance	0.045	0.065	0.12	0.085
Rejects	None	None	None	None
Relative Tolerance	1.3%	1.4%	2.1%	1.3%

TABLE V.

Aluminum Alloy	Type 356		
Element Analyzed	Silicon		
Number of Analyses per Sample	50		
Sample Number	86	87	88
Silicon Present	5.81%	6.80%	7.95%
Spectrograph Analyses:			
High	6.09%	6.89%	8.12%
Low	5.67%	6.61%	7.72%
Mean	5.90%	6.81%	7.95%
Standard Deviation	0.11	0.07	0.12
Tolerance	0.08	0.045	0.08
Rejects	None	None	None
Relative Tolerance	1.4%	0.7%	1.0%

Initial tests on a new spectrographic light source gave the following analytical results on a single sample:

TABLE VI.

Steel		
Number of Analyses	35	
Element Analyzed	Chromium	
Sample	National Bureau of Standards—Standard No. 30c	
Chromium Present	0.977%	
Spectrographic Analyses:		
Plate I	*Plate II*	*Plate III*
0.989%	0.978%	0.966%
.993	.981	.982
.990	.970	.969
.978	.971	.975
.962	.974	.980
.965	.989	.965
.969	.987	.978
.967	.978	.984
.987	.984	.966
.972	.970	.966
.984	.967	.978
.982	.978	

High	0.993%
Low	0.962%
Mean	0.977%
Standard Deviation	.00868
Tolerance	.00612
Rejects	None
Relative Tolerance	0.63%

Just as tolerances (maxima and minima) are established in specifications for acceptable chemical ranges, it is the practice at the Industrial Laboratory to set up analytical tolerances for the analyses themselves. These routine analytical tolerances are within the allowable specification range for the element under analysis and are made close enough to assure that the material under analysis by routine method is sufficiently correctly evaluated under an established procedure and that any single determination places the percentage of the element under analysis within or without a much smaller range than the entire specification range. "Tolerance" as used in the tables refers to this analytical tolerance. "Rejects" are determinations which are outside the analytical tolerance, but may be within the allowable specification range. Rejects may be carefully re-analyzed to determine acceptability. "Relative Tolerance" is the analytical "Tolerance" divided by the amount of the constituent present, multiplied by 100. The "mean" is simply the arithmetical average of the 50 analyses of which the "high" and "low" determination are also shown. "Standard Deviation" (root mean square deviation) is simply the square root of the average of the squares of the differences between the individual analyses and the "mean" and is a measure of the spread or scatter of the analytical results.

Tests for Accuracy.

Weekly check analyses on some routine samples are made in the Industrial Test Laboratory. These serve as checks on both method and personnel. The routine method is checked by re-analysis using careful and exact procedures. Results obtained by one operator are checked by having a routine analysis made by another operator, following the routine procedure exactly. Table VII gives the results of a typical weekly re-analysis check for accuracy.

TABLE VII.

Aluminum Alloy ..... Type 24S
Element Checked ..... Magnesium
Specification ..... 1.25% to 1.75%

Spectrographic Results (Routine Method)		Precise Chemical Method (Non-Routine)
1.67%	1.60%	
1.64	1.62	
1.62	1.54	
1.64	1.70	
1.68		
1.67		
Mean.....	1.65%	1.62%

It is of interest to note how the experience of other laboratories agrees with that of the Industrial Test Laboratory regarding the reliability of spectrographic results.

In the Journal of Applied Physics (1937), page 163, in describing the spectrographic laboratory at the Campbell, Wyant, and Cannon Foundry Company, Muskegon, Michigan, H. B. Vincent and R. A. Sawyer have this to say:

"Analyses for six elements are obtained from a single spectrum, the percentages covered being as follows:

Chromium	0.01% to 1.50%
Copper	0.20% to 3.00%
Manganese	0.30% to 1.25%
Molybdenum	0.07% to 1.50%
Nickel	0.15% to 2.00%
Silicon	0.50% to 4.00%

"If eight specimens are recorded on a single plate, the forty-eight analyses may be completed in about half an hour. The average accuracy of a single determination (relative tolerance) deviates from the actual amount present by not more than ±1% of the amount of the element present, and the maximum errors observed amount to less than five times the average uncertainty (relative tolerance)."

Two years later in 1939, using an improved modification of their original design, the same two authors, in describing the installation at the River Rouge Plant of the Ford Motor Company (Proceedings of the Seventh Summer Conference in Spectroscopy, John Wiley and Sons, 1940) have this to say:

"The schedule exceeds 300 samples in a sixteen-hour day; of course, not all samples are analyzed for all elements. Minimum time between receipt of a sample and posting the analysis results is six minutes. The average analysis time may exceed the minimum by something like a factor of two (or three).

The range of concentrations and elements for which analyses are made are as follows:

Chromium	0.01% to 3.5 %
Copper	0.20% to 4.0 %
Manganese	0.15% to 1.25%
Molybdenum	0.20% to 1.0 %
Nickel	.10% to 2.5 %
Silicon	.10% to 3.5 %
Tungsten	1.0 % to 8.5 %

Standard deviations, on multiple analyses of a single specimen average about 1.2 per cent of the concentration of the constituent present (i.e., the average relative tolerance is about 0.8 per cent)."

The upper limits in the range of concentrations of the elements analyzed is noteworthy. During a visit to this laboratory, the operation of which was briefly described earlier in this chapter, the authors learned that the number of specimens analyzed has been increased to about 300 per 8-hour shift, and that chromium and nickel are being analyzed successfully in concentrations up to about 15 per cent.

The foregoing discussions have been presented principally to indicate the applicability of spectrographic procedures to the routine determination of elements in the percentages normally encountered in ferrous and non-ferrous alloys with the exceptions of those high concentrations found in brasses and bronzes. The spectrograph, however, was first employed in the field of chemical analysis for the determination of trace or impurity elements. It was in fact the reliable analysis of very low concentrations of

such impurity elements as zinc, lead, copper and tin that introduced the spectrograph to this field. It is interesting to note that the spectrograph is used by the National Bureau of Standards in the preparation of Standard Samples. In these carefully analyzed Standards spectrograph methods are used to check the determinations of impurity elements.

In the routine analysis of such materials as zinc-base die casting alloys, zinc, high purity copper ingot, storage battery lead and pure pig tin, the merits of spectrographic analysis are even more outstanding as regards reliability, ease of execution, low cost and short elapsed time for determinations. The analyses of these materials involves the determination of elements present in concentrations of from 0.1 per cent to .0005 per cent. Such a determination as the concentration of bismuth in copper ingot, which is limited by specifications to a maximum of .001 per cent, is laborious and requires several days for completion by conventional chemical methods. By contrast, the spectrographic determinations of bismuth in copper ingot (.001 per cent max.) or cadmium in pure zinc (.005% max.) or silver in storage battery lead (.008 per cent max.) may be completed in a matter of minutes, with exactitude.

Qualitative Analysis.

While much of the foregoing has emphasized quantitative spectrographic analysis the value of the spectrograph for qualitative analysis should not be disregarded.

A qualitative analysis, by conventional chemical means, is a test of the ingenuity and skill of the chemist. He must search specifically for every element that may probably or possibly be present. The time consumed may be very great. Using the spectrograph, the entire spectrum is displayed on a plate in a matter of minutes. The experienced spectrographer will recognize the base metal or matrix, almost at a glance. He will then simply compare reference spectra with the unknown spectrum to determine the usual as well as the unusual or unexpected constituents. The value of the procedure is illustrated by an incident which occurred during the analysis of a specimen of welding electrode coating. In this analysis, by conventional methods, the presence of molyb-

denum, an objectional element in this particular coating, was overlooked. Fortunately the sample was subjected to qualitative spectrographic analysis and the presence of the molybdenum immediately detected. It is routine practice at the Industrial Test Laboratory to subject all qualitatively unknown specimens received to a spectrographic qualitative analysis before any other work on the specimen is started.

CHAPTER IV.

Comparison of Spectrographic and Conventional Chemical Analysis.

At the outset of any discussion of the factors involved in comparing spectrographic and conventional chemical analysis, it must be recognized that the purpose of this paper is not to suggest that spectrography become a general substitute for the chemical laboratory. It is rather to suggest the very useful correlation of the two procedures where the spectrograph may be used to augment the overall efficiency of the latter. However, it is also the desire of the authors to emphasize the importance of spectrography as a specialization of chemical analysis in which the spectrograph and its allied equipment are the principal instrumentalities for analytical procedures. The comparisons which follow are set forth to show that the advantages of this specialization, where applicable, are great.

In the foregoing chapters spectrographic installations at the Ford Company's River Rouge Plant and at the Campbell Wyant and Cannon Foundry were discussed. Similarly, installations at the Bethlehem Steel Company and many others might be cited. In all of these installations speed of analysis is paramount for the object of the determinations is to obtain immediate information on which to base additions to control the composition of melts of operating furnaces.

Though spectrographic analyses at the Industrial Test Laboratory are not performed for immediate production control, still, speed is all important. Samples are forwarded to this laboratory for analysis to determine conformance of materials with specification requirements. The results must be expeditiously reported

to the Naval Inspector in order that he may release materials for fabrication without delay.

Tables VIII to XIV which follow contain interesting information taken from the records of the Industrial Test Laboratory at the Philadelphia Navy Yard which emphasize the advantages of spectrography within the scope of its "specialized" applications.

TABLE VIII.

COST PER DETERMINATION

CHEMICAL METHODS OF ANALYSIS OF STEEL.

Element	*Labor*	*Material*	*Overhead*	*Total*
Mn	0.16	0.03	0.06	0.75
Si	.28	.06	0.11	.45
Cu	.28	.06	0.11	.45
Ni	.33	.07	.13	.53
Mo	.22	.04	.08	.34
Cr	.28	.06	.11	.45
V	.28	.06	.11	.45
W	.67	.13	.25	1.05
Cb	1.02	.20	.39	1.61
Ti	1.02	.20	.39	1.61
Sn	1.02	.20	39	1.61
Co	1.02	.20	.39	1.61

The estimates for overhead include maintenance, amortization in 15 years, and supervision, but do not include rent or taxes.

No estimates are given for occasional determinations such as lead or boron. The cost of these, particularly boron, may be three times as high as the most expensive one listed above.

The following table of costs covers some of the standard types of steels:

TABLE IX.

COST PER SAMPLE

CHEMICAL METHODS OF ANALYSIS OF STEEL.

Determinations	*Total Cost*
Mn, Si, Cu, Ni	$ 1.68
Mn, Si, Cu, Ni, Cr	2.13
Mn, Si, Cu, Ni, Cr, V	2.58
Mn, Si, Cu, Ni, Cr, V, Mo, W	3.97
All elements listed in Table VIII	10.41

TABLE X.

COST PER DETERMINATION

CHEMICAL METHODS OF ANALYSIS OF ALUMINUM ALLOYS.

Element	*Labor*	*Material*	*Overhead*	*Total*
Cu	$.22	$.04	$.08	$.34
Mg	.67	.13	.25	1.05
Zn	1.02	.20	.39	1.61
Si	.67	.13	.25	1.05
Ti	.67	.13	.25	1.05
Mn	.22	.04	.08	.34
Cr	.67	.13	.25	1.05
Per sample	4.14	.80	1.55	6.49

No estimates are given for occasional determinations such as lead, bismuth, nickel or beryllium. The costs of such analyses run much higher than any of those listed above. The cost of a beryllium determination may be very high and, in addition, require an especially skilled operator.

TABLE XI.

COST PER SAMPLE

SPECTROGRAPHIC METHOD OF ANALYSIS OF ALUMINUM ALLOYS.

Labor	*Material*	*Overhead*	*Total*
$.08	$.02	$.03	$.13

Complete figures are not available on the cost of spectrographic analysis of steel, because the installation to handle the complete analysis has just been installed. However, the costs of spectrographic analysis of steel are substantially equal to the costs of the analysis of aluminum for the same number of determinations.

The difference in cost of chemical methods for the various elements is of interest. The addition or subtraction of one determination may make an appreciable difference in the cost of analysis of a sample. These estimates are for routine work only. If an occasional sample is received that is of a non-routine character the cost of analysis may be three times as great.

The cost of a spectrographic determination is practically independent of the nature of the element being determined. The costs of all elements that can be determined in one spectrum are alike (an entire sample rarely requires more than two exposures). This is because the spectrographic method is substantially the same no matter what element is being determined. The addition or subtraction of a few determinations in any sample makes only a trivial difference in the cost of analysis.

Relative Time for Completion of Analysis.

TABLE XII.

STEEL ANALYSIS CHEMICAL METHOD.

Elapsed time to complete 1 batch of 12 similar samples.

Element	*Elapsed Time (in hours)*
Cu	12
Ni (low)	24
(high)	6
Mn	3
Si	8
W	12
Cr	2
V	3
Mo	2 (16 by H_2S method)
Co	12
Cb	16
Ti	16
B	32

Elapsed time for 1 man to complete 1 batch—78 hours.
Elapsed time for laboratory to complete 1 batch—24 hours.
Elapsed time for 1 man to complete 1 sample—30 hours.
The above times are actual elapsed times.

TABLE XIII.

ALUMINUM ALLOY ANALYSIS, CHEMICAL METHOD.

Elapsed time to complete 1 batch of 12 similar samples.

Element	*Elapsed Time (in hours)*
Cu	2½
Mn	2½
Mg	12
Si	6
Fe	5
Cr	3
Zn	9
Ti	2

Elapsed time for 1 man to complete 1 batch—28 hours.
Elapsed time for laboratory to complete 1 batch—18 hours.
Elapsed time for 1 man to complete 1 sample—15 hours.

Liberal estimates of elapsed time to complete analyses by spectrographic methods are given below:

TABLE XIV.

ELAPSED TIME TO COMPLETE ANALYSES BY SPECTROGRAPHIC METHODS.

Elapsed time for:
1 man to complete 12 samples—1½ to 2 hours.
Laboratory to complete 12 samples—1 hour.
1 man to complete 1 sample—¼ hour.
Laboratory to complete 1 sample—10 minutes.

As has been indicated by chemical methods, there is a wide difference in the elapsed time necessary to complete a single de-

termination of the various elements and even the same element when present in different concentrations or in different matrices. Such differences are not inherent in spectrographic methods. Within a tolerance of a minute or so, almost all elements are determined at uniform cost, regardless of the nature of the matrix. Thus, whether the element is to be determined in a sample of steel, aluminum, lead, or copper is relatively unimportant.

Relative Difficulty of Execution.

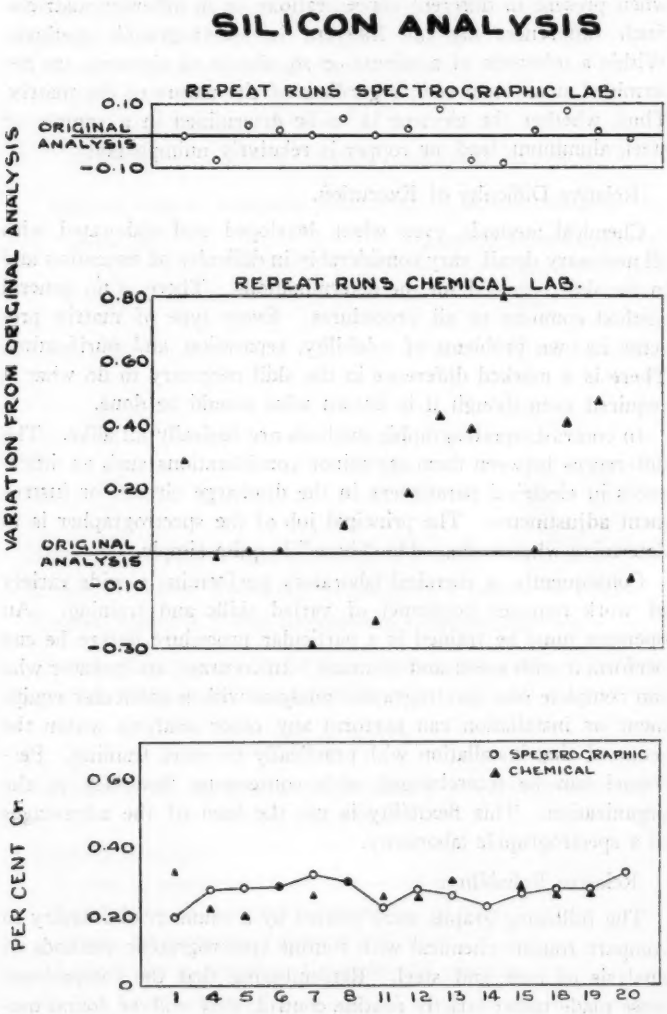
Chemical methods, even when developed and elaborated with all necessary detail, vary considerably in difficulty of execution and in the skill required for the determinations. There is no general method common to all procedures. Every type of matrix presents its own problems of solubility, separation, and purification. There is a marked difference in the skill necessary to do what is required even though it is known what should be done.

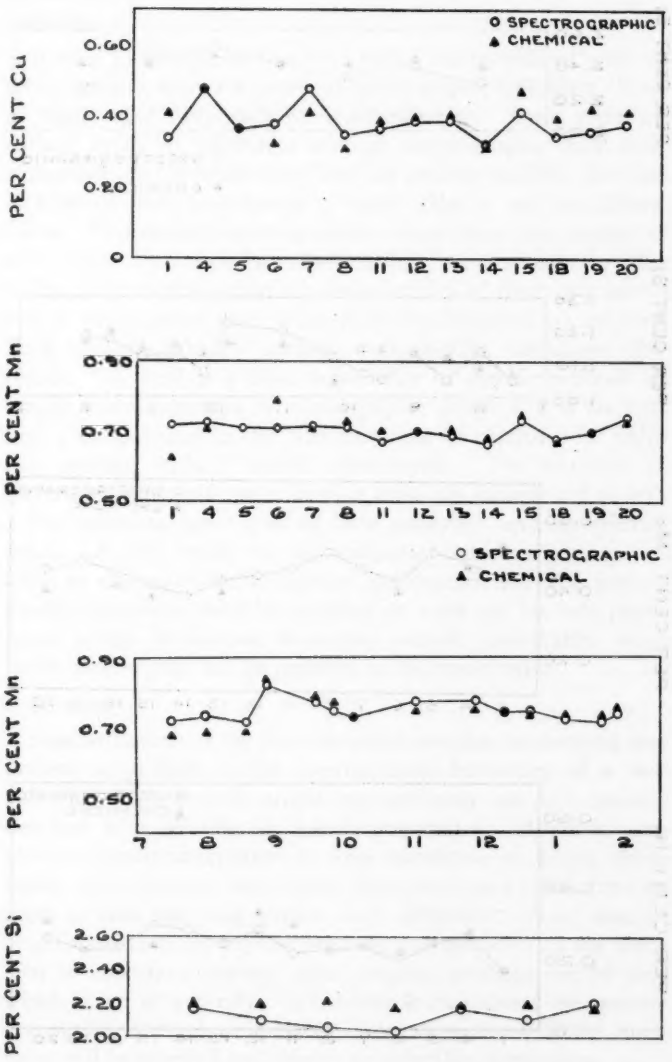
In contrast, spectrographic methods are basically all alike. The differences between them are minor considerations such as differences in electrical parameters in the discharge circuit, or instrument adjustments. The principal job of the spectrographer is to determine what to do. The "how" is quite simple.

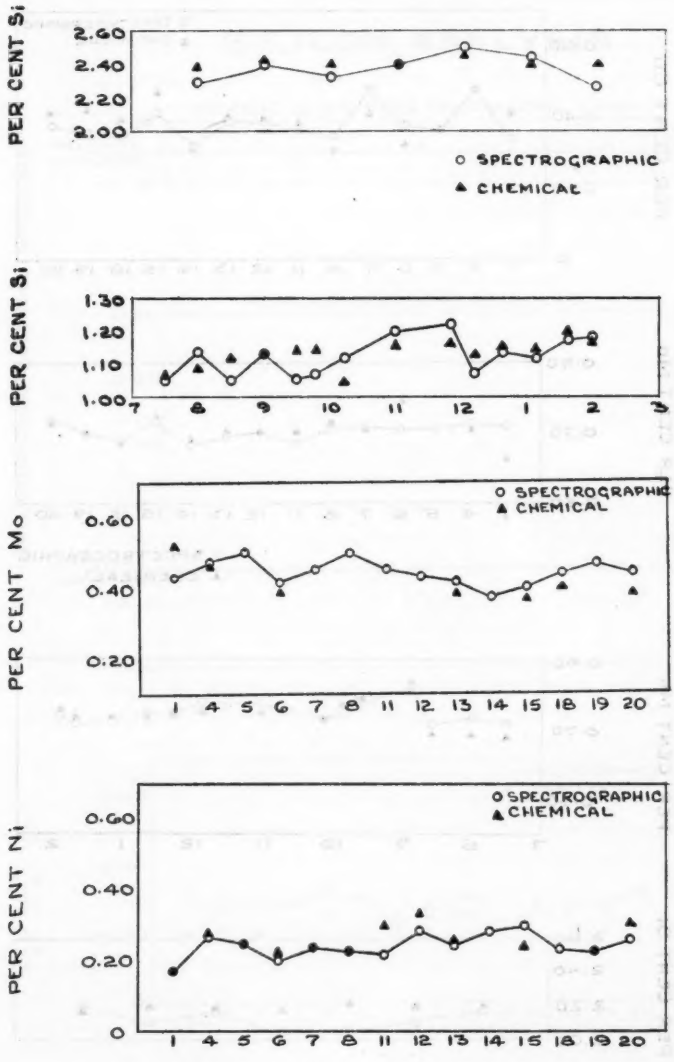
Consequently, a chemical laboratory performing a wide variety of work requires personnel of varied skills and training. An operator must be trained in a particular procedure before he can perform it with speed and accuracy. In contrast, an operator who can complete one spectrographic analysis with a particular equipment or installation can perform any other analysis within the scope of that installation with practically no extra training. Personnel can be interchanged with consequent flexibility in the organization. This flexibility is not the least of the advantages of a spectrographic laboratory.

Relative Reliability.

The following graphs were plotted by a commercial foundry to compare routine chemical with routine spectrographic methods of analysis of iron and steel. Remembering that the comparisons were made under strictly routine control, they will be found useful in indicating relative reliability of the two methods.


SILICON ANALYSIS
REPEAT RUNS SPECTROGRAPHIC LAB.
0.10
ORIGINAL ANALYSIS
-0.10
REPEAT RUNS CHEMICAL LAB.
VARIATION FROM ORIGINAL ANALYSIS
0.80
0.60
0.40
0.20
ORIGINAL ANALYSIS
-0.10
-0.30
O SPECTROGRAPHIC
▲ CHEMICAL
PER CENT Cr
0.60
0.40
0.20
0
1 4 5 6 7 8 11 12 13 14 15 18 19 20
PER CENT Si
PER CENT Mn
PER CENT Mn
PER CENT Cu


O SPECTROGRAPHIC
▲ CHEMICAL
PER CENT Cu
0.60
0.40
0.20
0
1 4 5 6 7 8 11 12 13 14 15 18 19 20
PER CENT Mn
0.90
0.70
0.50
1 4 5 6 7 8 11 12 13 14 15 18 19 20
O SPECTROGRAPHIC
▲ CHEMICAL
PER CENT Mn
0.90
0.70
0.50
7 8 9 10 11 12 1 2
PER CENT Si
2.60
2.40
2.20
2.00


PER CENT Si
2.60
2.40
2.20
2.00
○ SPECTROGRAPHIC
▲ CHEMICAL
PER CENT Si
1.30
1.20
1.10
1.00
7 8 9 10 11 12 1 2 3
PER CENT Mo
○ SPECTROGRAPHIC
▲ CHEMICAL
0.60
0.40
0.20
1 4 5 6 7 8 11 12 13 14 15 18 19 20
PER CENT Ni
○ SPECTROGRAPHIC
▲ CHEMICAL
0.60
0.40
0.20
0
1 4 5 6 7 8 11 12 13 14 15 18 19 20

Limitations of Spectrographic Procedures.

Methods.

It must be recognized that even within the specialized scope of spectrography, there are problems which present difficulties. Some of these arise from lack of standardization. Since there are various types of excitation sources, spectrographs, dark room equipment, and densitometers that are entirely suitable, the combination of these instruments is rarely alike in any two laboratories. Experienced spectrographers rarely allow the passage of more than a few months without making some change or other in the mechanical or electrical characteristics of their instruments and in consequence many home-made modifications are imposed. Such initiative, though perhaps commendable, introduces difficulties. As there is a close dependency of specific methods on specific instrumentation in spectrographic analyses, it is doubtful that a method used in one laboratory can be carried over bodily into another, without careful adjustments. The literature on spectrographic specific procedures is relatively meager and in only a few instances has a method been published with all relevant detail. As the result of the foregoing considerations, anyone about to undertake the installation and organization of a spectrographic laboratory must be prepared to work out his own procedures unless he chooses to employ outside consultants, which choice may or may not be practical in his organization.

Specimens.

Standardization of the form in which samples are received may present no problem to the spectrographic laboratory of a steel mill whose heat or melt samples are uniformly cast to a specified size and form suitable for speedy preparation. However, samples for identification taken in some warehouse or during fabrication, from the rods, bars, sheets plates or shapes rolled from an ingot of that heat may present real difficulties. Since spectrographic methods are physical methods, the geometry of the specimen is important (except where solution methods can be used which is not in general). It is probable that unless the spectrographic laboratory is a producer's laboratory, non-uniform specimens will be received and require considerable preparation.

Standards.

Routine spectrographic determinations are the result of methods of interpolation. Measurements on the spectrum of the specimen being analyzed are interpolated between measurements on spectra of standard specimens whose composition is known. Consequently, the accuracy of any determination depends on the accuracy of analyses (by chemical methods) of the known standard specimens. The preparation of these standard specimens suitable as to chemistry and physical form is inherently a painstaking job. Further, the closer the permissible tolerances that are placed on the precision of spectrographic analyses, the closer must be the approximations of the standard to the specimen being analyzed—both in composition and in form. It is well to note, however, that, for routine analyses, the primary purpose of which is to determine that the percentage of an element is within the specification limits for that element, the reporting of a close approximation of the percentage is sufficient.

Elements.

Emission spectrographic procedures as previously indicated are limited to metallic or metalloid elements. Molecular compounds are not distinguishable. Iron, for example, as metallic iron, as iron oxide, or iron in hemoglobin all produce the same spectra which is the atomic spectrum of iron. However, in metallurgical analyses, elementary composition is all that is usually required.

Concentration of Elements.

Though under some conditions a concentration of an element higher than 10 per cent can be determined satisfactorily, in general the upper limit for good analysis is about 10 per cent. The spectrographic tolerance for higher amounts may exceed permissible specification variation. Spectrographic analyses generally increase in accuracy and precision as the concentration of the element decreases, which is directly opposite to the way in which most chemical methods behave.

CHAPTER V.

Organization of a Spectrographic Laboratory.

Because of the basic similarity of all spectrographic methods for routine control, the organization of such a laboratory as re-

gards personnel is quite simple. The line organization discussed here begins with the laboratory director. Administration above that point is similar to any other organization.

Two types of technical personnel are necessary. The relative numbers of each type will depend on the specific nature of the work expected of the laboratory and on the extent of this work. These types may be classified as follows:

(*a*) Laboratory Technical Director and (if required) associate technical personnel capable of devising methods, modifying equipment, making investigations and checking the accuracy of procedures, standards, and operating personnel.

(*b*) Operation group who perform the routine procedures set up by the (*a*) group.

As was pointed out in the previous section, a newly organized laboratory may "get under way" more quickly either through the employment of "outside" consultants or by employing a technical director. Unless the installation is established for a specific, rather invariable objective requiring few changes in procedures or equipment, it is believed that the employment of a director to be placed right in the laboratory will be found to produce more satisfactory results from the long-range viewpoint. The director should take advantage of available detailed information from all sources. An estimation of the qualifications of such a director will be set forth. The scientific or technical experience of this man might be evaluated as follows:

Chemistry, 15 per cent.
Physics, 50 per cent.
Practical Ingenuity, 35 per cent.

He need not be an experienced chemist as what is ordinarily called chemistry is but little involved in spectrographic methods. Proper adjustments of details in spectrography (and it is such adjustments that control the accuracy of quantitative analyses) belong as a rule in the fields of electricity, optics, and shop practice. The technical director should be capable of:

(*a*) Determining the form and accuracy of chemically known standards and setting up spectrographic standards.

(*b*) Devising and putting into use suitable procedures or of adapting specific procedures to his needs.

(*c*) Making such procedures consist of simple mechanical unit operations and avoiding highly critical or sensitive control in any operation.

(*d*) Coordinating all phases of spectrographic analyses.

(*e*) Supervising preparation of curves or of preparing them himself.

(*f*) Improving or adjusting methods as conditions demand.

(*g*) Research as well as development and therefore he must become cognizant of and keep abreast of developments in spectrography.

(*h*) Hard work and a consuming interest in his work.

The laboratory will advance in efficiency to the extent of the director's ability, zeal, and interest. It is his function to answer the questions as to what to do as well as how.

Operating Group.

Little technical ability or special skill will be required for the operating group. Bright, alert high school boys or girls will be found quite satisfactory. Within a few weeks at most such personnel can be taught to perform all operations well enough to attain peak speed and accuracy. This group must be impressed with the necessity of following meticulously the simple instructions for the performance of simple operations without deviation, but should be capable of detecting and instructed to report any "out of line" tolerance of instruments. The why and how should be generally discussed with operators to create interest in their routine operations. Such discussions may create a type of interest that will pay dividends in suggested improvements in the routine. In this connection the director or one of his associates should be as thoroughly familiar with routine details as the operators themselves.

Availability of a Chemical Laboratory.

Occasionally a specimen "will fall out of line" or show erratic behavior. It may be advantageous to know, by chemical methods, the exact composition of that specimen. Standards may require occasional checking or new standards may become neces-

sary. For these purposes a chemical laboratory capable of accurate determinations should be available. It is also advantageous to make occasional comparisons of routine spectrographic results with routine chemical results. Some specimens may contain elements in too high a percentage for satisfactory analyses by spectrographic methods. Non-metallic elements such as carbon and sulphur are not amenable to spectrographic analyses. It is therefore advisable that the services of a suitable conventional chemical laboratory be available.

Types of Installations.

Specific types of installations with choice of instruments to suit the specific assignment of a laboratory are necessary. Some typical installations employing equipment of current design for analyses of various materials follow:

1. Steels.

(*a*) High accuracy required.

(*b*) Percentages as high as 15 per cent Cr. and 15 per cent Ni.

(*c*) Workload, 1000 specimens per 24-hour day.

Spectrograph. Large Littrow made by Bausch & Lomb Company, Rochester, New York, or by Hilger Company, London, England.

Excitation Source:

(*a*) Controlled, condensed spark, 35,000 volts, and

(*b*) a-c arc, 2200 or 4400 volts, 3 to 6 amperes.

Precise rugged excitation sources of the two types listed above have been designed and can be procured from the Department of Engineering Research of the University of Michigan, Ann Arbor, Michigan. These units are at present made to suit the user's requirements. The power circuits are substantially similar, the differences being primarily in those of control and flexibility of the various power circuit units.

Similar types are available from H. W. Dietert Company, Detroit, Michigan (Applied Research Laboratories of Glendale, California).

Densitometer

If a laboratory is installed to check the product of furnace melts, a non-recording, galvanometer deflection densitometer will be found to have better speed characteristics. A satisfactory unit of this type is made by the Department of Engineering Research, University of Michigan. It is understood that negotiations have been started by the University to have this unit produced by a commercial instrument manufacturer.

If the rapid posting of individual reports is not important, i.e., if the specimens can be handled in groups, a satisfactory densitometer is the Knorr-Albers Microphotometer, recording type, made by the Leeds and Northrup Company of Philadelphia, Pennsylvania.

Dark Room Equipment.

Mechanically agitated or rocking development trays are advisable. Such equipment can perhaps best be made by the direct efforts of the laboratory concerned.

An infra-red lamp drier, or a blower drying device, is advisable for rapid drying of photographic plates.

Analytic Equipment.

For rapid computation of analytical results, it is advisable to prepare nomographic charts or multiple slide rules such as those mentioned in the foregoing sections.

Spectrum Microscope.

If standard reference plates are not available, it is advisable to procure a spectrum measuring microscope similar to the one manufactured by the Bausch and Lomb Optical Company. This is necessary for the precise measurement of the linear intervals between spectrum lines to determine their exact wave lengths. A copy of "Wave Length Tables" Harrison (John Wiley Sons, N. Y.) is indispensable to all spectrographic laboratories.

Miscellaneous.

Specimen grinders.

Pellet press.

Viewing boxes, hand lenses, graphite electrodes, etc.

The normal operating crew, for an installation as described,

for high speed production consists of four operators, one at the spectrograph who grinds or prepares the specimen and makes the exposures; one in the dark room who develops and prepares the photographic plate, one at the densitometer who measures the selected line and one who computes and posts the analytical results.

2. Aluminum Alloy Control.

Aluminum alloys are chosen as typical of non-ferrous alloys. Other alloys of this group are those of magnesium and lead.

Spectrograph.

Medium quartz as made by Bausch and Lomb Optical Company or Hilger Company of London, England.

Excitation Source.

Controlled, condensed spark, 30,000 volts.

Simple spark generator, condensed spark at 17,000 volts, as made by Bausch and Lomb.

a-c arc, 2200/4400 volts, 3 to 6 amperes.

The other units as described under steel.

3. Zinc Alloy Control.

Spectrograph. Medium quartz.

Excitation Source. 220-volt. d-c arc, at 10 amperes. The current is controlled by a rheostat or similar device.

Densitometer. None may be required.

Dark Room, etc. Similar to those described under steel.

A chemical table and hood are required, for the usual preparation of zinc specimen which are prepared by dissolving zinc in acid. A drying oven is also required.

4. Mineral or non-metallic specimen analysis.

Spectrograph. Complex minerals: A grating spectrograph, similar to the 3-meter grating spectrograph made by Baird Associates of Cambridge, Massachusetts.

Excitation Source. 220-volt, d-c arc, at 10 amperes. The current is controlled by a rheostat or similar device.

Densitometer. A suitable densitometer is the Optical microdensitometer made by the Gaertner Scientific Company of Chicago, Illinois.

Dark Room Equipment. Similar to those previously described.

Miscellaneous. Graphite electrodes, semi-micro balance, pellet press.

In relation to the above the following characteristics should govern the choice of a spectrograph:

1. Highest optical speed.
2. Sufficient dispersion.
3. Rugged construction.

Grating spectrographs can be used in place of prism instruments. Until very recently there were practically no grating spectrographs commercially available. That fact gave rise to a wide distribution of prism instruments and most published routine methods are consequently based on instruments of that type.

A spectrograph of higher dispersion can be used when a lower dispersion instrument would suffice. Thus a large Littrow spectrograph can be used for the analysis of aluminum alloys. However, the optical speed of the medium quartz spectrograph is about 10 to 15 times as fast as the large Littrow and its use is thus advisable where a lower dispersion is satisfactory.

As stated earlier, it is again emphasized that the arrangement of a spectrographic laboratory should be carefully considered so that no time is lost in moving over distances greater than necessary.

The Industrial Test Laboratory.

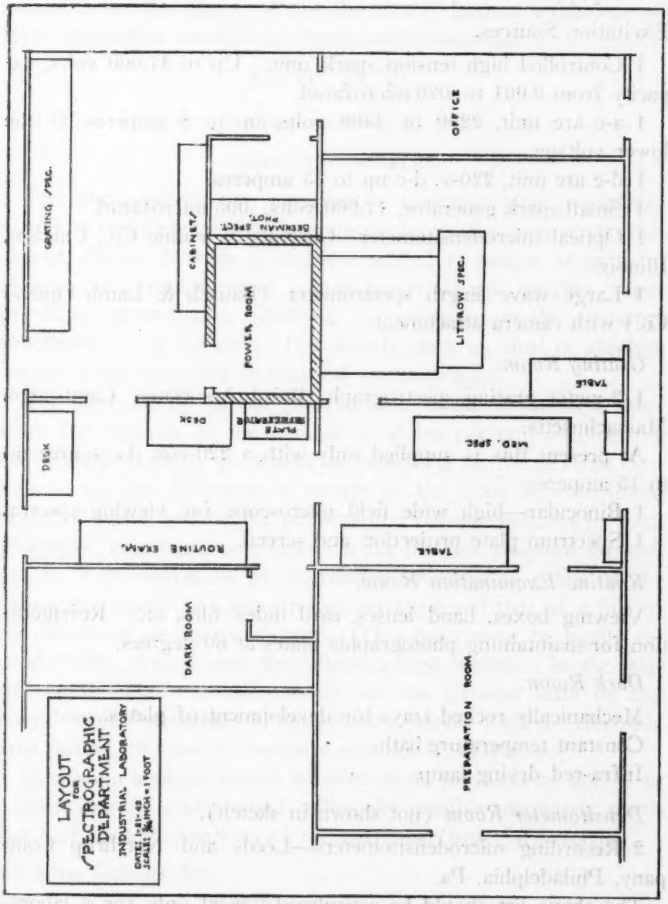
The layout of the spectrographic section of the Industrial Test Laboratory at the Philadelphia Navy Yard is indicated in the accompanying sketch. One detached room, containing two Leeds and Northrup Recording microdensitometers is not shown. In this laboratory the following equipment is available for routine use:

Preparation Room.

1. Steel pin grinder.
2. Belt grinders for aluminum specimens.

Medium Spectrographic Room.

1 Medium Quartz spectrograph (Bausch & Lomb Optical Co.)
1 Spark generator, Bausch & Lomb Optical Company, 17,000 v.
1 Arc source, 220-v. d-c up to 25 amperes.


OFFICE
GRATING SPEC.
CABINETS
DENMAN SPECT. PHOT.
POWER ROOM
LITTROW SPEC.
TABLE
DESK
PLATE REFRIGERATOR
DESK
MED. SPEC.
ROUTINE EXAM.
TABLE
DARK ROOM
PREPARATION ROOM
LAYOUT FOR SPECTROGRAPHIC DEPARTMENT
INDUSTRIAL LABORATORY
DATE: 1931-01
SCALE: 3/8INCH=1FOOT

Littrow Spectrograph Room.

1 Large Littrow spectrograph (Bausch & Lomb Optical Co.).
1 Equipped with quartz and glass optics.

Excitation Sources.

1 Controlled high tension spark unit. Up to 47,000 volts, capacity from 0.001 to .020 microfarad.

1 a-c arc unit, 2200 or 4400 volts, up to 8 amperes, at the lower voltage.

1 d-c arc unit, 220-v. d-c up to 25 amperes.

1 Small spark generator, 17,000 volts, .005 microfarad.

1 Optical microdensitometer—Gaertner Scientific Co., Chicago, Illinois.

1 Large wave length spectrometer (Bausch & Lamb Optical Co.) with camera attachment.

Grating Room.

1 3-meter grating spectrograph, Baird Associates, Cambridge, Massachusetts.

At present this is supplied only with a 220-volt d-c source up to 15 amperes.

1 Binocular—high wide field microscope for viewing spectra.
1 Spectrum plate projection and screen.

Routine Examination Room.

Viewing boxes, hand lenses, card index files, etc. Refrigeration for maintaining photographic plates at 60 degrees.

Dark Room.

Mechanically rocked trays for development of plates.
Constant temperature bath.
Infra-red drying lamp.

Densitometer Room (not shown in sketch).

2 Recording microdensitometers—Leeds and Northrup Company, Philadelphia, Pa.

The above list should be considered typical only for a laboratory such as the Industrial Test Laboratory where both research and volume routine spectrographic analysis of many and varied materials have to be carried on in an expeditious manner. Nego-

tiations have been initiated with various manufacturers, to prepare a selected group of standardized instruments for the particular needs of Navy Laboratories. The advantages of such standardization of installation is obvious in any general expansion of spectrography in the field of inspection of materials.

CHAPTER VI.

INSTRUMENTS.

EXCITATION SOURCES.

The ideal source for quantitative spectrographic procedures would be one in which all elements in the specimen enter the discharge, diffuse through it, and are excited to radiate at uniform relative rates, regardless of boiling points, atomic weights, vapor pressures or excitation functions; of variations in the discharge conditions; or of the time. Fortunately, such an ideal or absolute source, is not necessary in practical spectrography.

The intensity of the hot gas radiation which produces a spectrum line depends on the number of atoms per unit volume, the transition probability (a parameter depending on the electron configuration), the difference in energy of the atom between initial and final states, and on the temperature. Most quantitative spectrographic procedures are based on the *internal standard method,* i.e., on a determination of the relative intensity of a line of the substance present in unknown concentration and that of a line of the reference or matrix element. This ratio must be highly reproductible. Any source that allows a high variation in the relative amounts of material carried into the gaseous state or any considerable fluctuations in temperature, locally over the electrode area during the time of exposure will not be satisfactory.

Excitation sources should be selected on the basis of ability to provide arcs or sparks which will make possible adequately sensitive and accurate analyses of the particular material involved.

d-c Low Voltage Arc.

It must be recognized that the d-c arc is erratic and variable and one of the most difficult with which to obtain accurate results. The arc column consists of a bright hot central core surrounded by an envelope or halo of cooler gas. At the anode, the dis-

charge concentrates at a small intense anode spot, whose size depends on such factors as the anode material which must supply the electrode emission to maintain the arc, current strength and gas atmosphere. The chief source of variability in the arc appears to be the wandering of the anode spot with accompanying instability of the discharge. Examination of the current and potential differences of such arcs, with an oscillograph has shown extremely rapid spasmodic and irregular variations of both current and voltage as high as 50 per cent in opposite directions. Such variations cause fluctuations in the release of electrode material and in the temperature at the disengaging point, and in the time of disengaging. As a result elements with different boiling points enter the discharge at different rates and time intervals, and fluctuations both in the total and in the relative number of the different kinds of atoms entering the discharge results. The variations in the numbers of atoms entering the arc column causes variations of arc both in intrinsic brilliancy and in total intensity as well as in the relative distribution of intensity among the different spectral lines.

Quantitative analysis with the d-c arc is based on the probability that the variations will average out over the whole exposure in a fairly reproducible manner. Often results from two or more exposures are averaged. If the material is placed in a cavity in a graphite electrode and burned to exhaustion, the total number of atoms may be controlled in a more uniform manner. Iron and steel show especially unfavorable action in the d-c arc. In general high accuracy has seldom been claimed for analysis with a d-c arc.

The assembly of an arc is simple. A 230-volt power source is preferable to one of 115 volts. The current may be controlled by a variable resistor in series. The resistor used in the Industrial Test Laboratory is a heavy duty carbon pack. If no d-c supply is readily available, a motor-generator set must be used.

Many attempts have been made to stabilize the d-c arc. Decreasing the area of the electrodes, or increasing current density offers a marked improvement. Rotating the iron anode to throw off droplets of molten iron has also been tried. A high voltage d-c source, about 2200 volts with a large stabilizing series resistor, has

been used. All these modifications offer some improvements over the simple 220-volt d-c arc, but voltage fluctuations and wandering of the cathode spot still occur and require attention.

Interrupted High Voltage d-c Arc.

Some very recent work has been done on the use of an interrupted high voltage d-c arc. The arc potential is periodically cut off by the use of a rotating switch and restarted with a spark discharge similar to that from a Tesla coil. This type of unit is expected to be incorporated in a source installation by Bausch & Lomb Optical Company under the trade name of "Spectrosource."

a-c Arcs.

Another approach to stabilization consists of using a high voltage (2200 volts/4400 volts) a-c arc. Oscillographic observations show for this source a nearly sinusoidal variation of the current while the voltage shows peaks at the break and re-ignition of the arc. Each new half cycle starts with a glow (probably with some explosive release of electrode material, as in a spark discharge) followed by transition to an arc. The wandering of the anode spot is controlled in that it is forced to re-establish itself at each half cycle. The result is a form of arc which is considerably more reliable than the simple d-c arc. An arc of this sort can be ignited with a spark from a Tesla coil.

Discussion of Arc Sources.

The a-c arc may be thought of as an uncondensed spark with a sinusoidal current of low frequency and of constant amplitude fixed by the applied voltage and resistance. In the condensed spark there is (at each transformer half cycle) an oscillatory discharge with a frequency which may be anything up to hundreds of thousands of cycles per second and with a current that may reach an amplitude of hundreds of amperes in the first cycle, damped rapidly in succeeding cycles.

The behavior of voltage and current is much like that in the a-c arc, but with much higher frequency and with a decrement of current which depends on the rate at which energy is lost in the spark circuit and in the spark itself. Studies of the spark

with a rotating mirror show that material is released simultaneously from each electrode—presumably by ion bombardment—and moves out into the spark gap as a luminous streamer. The succeeding arc-like discharge is an electrode vapor which radiates the spectrum of the electrodes.

The energy input to the spark must oscillate with the spark frequency and with a diminishing amplitude and therefore there must be an oscillating temperature with corresponding decrement. The average temperature has been determined to be about 8000 degrees C. to 10,000 degrees C. for discharges between a point and a plane electrode.

For accurate analysis it is desirable to have the same voltage (energy) at the initiation of each spark train and the same decrement of current in each train. This insures uniformity of the number of energized atoms per unit volume of arc since equal initial energy is used to release electrode material. A uniform average temperature results because of uniform maximum energy and uniform decrement. A few seconds of presparking before exposure of the plate serves to "outgas" the electrodes, to form an oxide on them, to smooth their surfaces and to establish some sort of temperature equilibrium.

Many successful analyses are performed with simple a-c spark sources such as those made by the Bausch & Lomb Optical Co. The Circuit parameters are: 120 volts to 15,000 volts, power about 450 v.a., capacity .005 micro-farad, inductance 0 to 20 microhenrys in 5 steps. The transformer is of the type used for luminous signs.

It is highly desirable, in spark analysis, that the energy in the condenser at the initiation of each spark train be the same. One method of approximating this condition, devised by Feussner, is to place, in series, in the high voltage side of the spark circuit, a synchronously rotating gap or interrupter which is so timed that the sparking takes place only during a few degrees of motion of the gap, always at the same phase and voltage of the condenser cycle. An air blast on the gap and a series resistance in the spark circuit serves to control the damping.

Recently there was installed at the Industrial Test Laboratory a spectrographic light source designed and constructed by the De-

partment of Engineering Research of the University of Michigan, Ann Arbor, Michigan. This source is designed to supply high voltage spark and alternating-arc excitation. Provision has been made for the use of two control stations if desired, one to use the arc and the other the spark interchangeably.

The electrical characteristics of this source are briefly described as follows:

SPARK SOURCE.

Transformer: A 15 KVA-G.E. oil filled transformer 220v/33,000 volts.

Capacity: From .001 to .020 microfarad. The condenser is built of glass plate and sheet metal and is oil immersed and water cooled.

Inductance: A coil of about 9 inches diameter and about 30 inches high with taps provided for adding from 0 to 60 turns in five steps.

Control: A synchronous motor operates on interrupter in the secondary circuit.

ARC SOURCE.

Transformers: Two 7.5 KVA-G.E. Transformers 220v/2200 volts connected in parallel on the primary side. (The secondarys may be used in series or parallel thus giving an arc of 2200 volts or 4400 volts.)

Resistance: Two banks of copal wire wound resistors, each up to 1500 ohm. Each bank is subdivided into approximately five equal steps controlled by two sets of five switches. The resistance can thus be varied up to 750 or 3000 ohms in the parallel and series connections respectively.

Arc Starter: A Tesla coil is used to start the arc.

Controls: The applied voltage can be varied from 110 to 220 volts by a variac. A voltmeter and ammeter are placed in the primary circuit. The excitation transformer and condenser are housed in a fireproof cubicle, the door of which is protected by an electrical interlock and limit switch. The control panel has a lock, start and stop push buttons.

The electrodes are inclosed in a wood box, the door of which operates a trap limit switch.

Provision is made, to operate the time of excitation, Tesla starter and pre-spark shutter manually or automatically by electric timers.

Signal lights are provided to indicate the electrical state, i.e., *ready, arc, spark* and *on.*

All power is controlled by relays operated from a remote control push button station.

Mechanical Features.

The condenser, the main switch in the secondary used to change from arc to spark, the arc resistances, etc., are mounted on a steel frame with slate and wood panel fronts.

The electrode clamps are of stainless steel and are movable over a distance of 160 cm. A scale is provided to indicate the distance of the gap from the spectrograph.

Methods for routine analysis of an element must be devised not merely for materials that remain substantially constant in composition with only small variations in concentration of a few elements, but also for the analysis of that element in materials that vary widely in composition. For example, a routine method must be devised to determine the manganese content of a certain type of mild steel. A method for analysis of manganese in corrosion resisting steel or in high speed tool steel must also be devised. Manganese must also be determined in aluminum or magnesium alloys. Widely varying amounts of different elements may affect the temperature of the discharge by altering the heat conductivity, heat content or rate of radiation of the discharge. The different ionizing potentials and transport rates may affect the potential gradient in the column. The different masses and boiling points may affect the rate at which the elements are released at the electrodes. These factors may affect the accuracy of the determination of an element. However, the less the variance of the excitation source the lower the effect of these factors and the greater the reproducibility of the method. Excitation and its control is the most sensitive part of spectrographic methods. No procedure should be expected to produce accurate results which does not adequately provide for excitation control.

The usual excitation sources, in order of increasing sensitivity and decreasing reproducibility, are: The a-c spark, the a-c arc and the d-c arc.

The choice of a light source should be that source which, within the limits of permissible tolerance of external conditions, will behave in the most uniform and reproducible manner and have the requisite sensitivity.

Some commercial units and their manufacturers follow:

Simple a-c Spark Units:

Bausch & Lomb Optical Co., Rochester, New York, and
Baird Associates, Cambridge, Massachusetts.

Simple d-c Arc (low voltage) Units:

Baird Associates, Cambridge, Massachusetts, and
H. Dietert & Co., Detroit, Michigan.

a-c Arc Units (2200 volts):

Baird Associates, Cambridge, Massachusetts, and
H. Dietert & Co., Detroit, Michigan.

a-c Spark, Feussner Circuit:

H. Dietert & Co., Detroit, Michigan.

Special a-c Arc and Spark, Feussner Circuit:

Department of Engineering Research, University of Michigan, Ann Arbor, Michigan.

Spectrographs.

The spectrograph is the central instrument about which all spectrographic procedures are constructed. A discussion of the optical theory of such instruments is too involved for the space and time limitations necessarily imposed on the authors. The details may be found in texts on advanced optics and physics. It must suffice here to discuss the suitability of some of the commercially available instruments, for the analyses to be performed and as to mechanical ruggedness and ease of operation.

The purpose of a spectrograph is twofold, first to separate the light or radiation, emitted by the excitation source, into its component wave lengths. The second is to record these components as perfectly focused lines on a photographic plate with no fog-

ging due to scattered light. The spectrograph must perform these functions in a minimum of time. Ease of control and sufficient ruggedness to insure stability are prime mechanical requirements.

While various optical and mechanical arrangements are found in commercial instruments, the essential components are four: The slit, lenses, dispersing element, and the photographic Unit.

From a functional standpoint it is important to consider the following characteristics of the spectrograph: dispersion and resolving power, optical speed, freedom from fog due to scattered light, ruggedness, and ease of control.

Brief consideration will be given to the component parts before considering the various instruments themselves.

The Slit. A well-made slit is essential to the proper functioning of a spectrograph. The jaws should be straight, ground to optical tolerances, strictly parallel and made of corrosion resistant material such as stellite or stainless steel to assure permanence of the sharply defined edges.

The necessity for parallelism is evident when it is considered that slit widths as narrow as 0.02 mm. are used. Slit widths may be fixed or adjustable. If fixed widths are used, about five sets of slits are necessary in ordinary routine work, ranging from 10 microns to about 100 microns in width. Adjustable or movable slits are made with one movable jaw or, as is more common with both jaws movable (the bilateral slit). Close precision and exact workmanship are necessary in making the moving parts of bilateral slits to maintain parallelism and to provide reproducible settings.

The Lenses. The lenses, as well as all other optical parts of a spectrograph should (unless specifically desired otherwise) be of the highest grade of crystal quartz. Glass is opaque to the ultraviolet end of the spectrum, a portion most frequently used in metallurgical analysis. The usual lenses required are:

A condensing lens to focus the light on the slit and dispersing element,

A field lens just in front of the slit is sometimes used,

A collimating lens to make certain that the light striking the dispersing element (if a prism) is parallel, and

A camera, objective or telescope, lens to focus the dispersed radiation on the photographic plate.

The Dispersing System.

The function of this unit is to break up, analyze or disperse the incident radiation from the arc into its component wave lengths. In prism spectrographs dispersion is accomplished by using the property of quartz or glass to refract or bend light. The amount of refraction varies with wave length. A proper geometrical arrangement of the faces of a prism will deviate a ray of light from its original direction, by an amount that is proportional to its wave length. A grating or concave mirror ruled about 15,000 or 20,000 lines to the inch, will also "break up" light and deviate a ray from its original direction by an amount proportional to its wave length. There are two important differences in the manner in which prisms and gratings disperse light. The difference in deviation of two beams by a grating is exactly linearly proportional to their difference in wave length. A prism deviates light of shorter wave length a greater amount than light of longer wave length.

Secondly, a prism deviates a ray of certain wave length only once. A grating deviates a ray a number of times with decreasing dispersion (angstroms per millimeter). Thus in a grating spectrum, at about 9000 A, there are found lines of wave length 9000 A with a certain dispersion d, with lines about 4500 A with a dispersion ½d and lines about 3000 A with a dispersion ⅓d and so on. These multiple deviations are called *orders*. The intensity of the dispersed beam decreases in the higher orders.

This property of a grating can be used to good advantage when working with complex spectra, with many lines close together. It is possible to go to a higher order, if the intensity of the light is sufficient, to obtain spectra with 1/2 or 1/3 or as low as 1/6 the original dispersion.

Prisms are usually made with an equilateral triangle as the base. These are called full or whole prisms. Prisms with base angles of 90 degrees, 60 degrees and 30 degrees (as used in the Littrow mounting) are known as half prisms.

The Photographic Unit.

The photographic plate must be housed in a rugged well-made cassette or plateholder. The back of the cassette should be curved to fit the shape of the focal curve.

FUNCTIONAL FEATURES OF A SPECTROGRAPH.

Dispersion and Resolving Power.

A spectrograph should spread out the lines on a plate sufficiently to prevent overlapping and to allow the spectrum to be used without enlargement by projection. The amount of dispersion necessary for ready workability (angstroms per millimeter) depends on the type of material being analyzed; however, approximate estimates for sufficient dispersion might be: for non-ferrous metals (Al, Mg, Cu, Pb, Sn, Zn), 10 to 15 A per mm.; for steel, 5 A per mm.; for complex spectra such as W, V, Mo, about 2 to 3 A per mm.

The resolving power, or optical ability of the spectrograph to separate close lines, should be high enough to match the dispersion.

Optical Speed.

The optical speed should be as high as possible for the dispersion necessary to resolve the spectrum. Maximum exposure should be in the neighborhood of one to two minutes, if density is the only requirement.

Freedom from Fog Due to Scattered Light.

The optics should be so arranged that scattered light is kept at a minimum. This requires the judicious use of baffles.

Ruggedness.

The spectrograph should be built on a rugged, substantial base. The alignment should not be affected by minor vibrations or temperature changes. Most commercial spectrographs are built well enough to meet these requirements. However, some mechanical difficulty is probable with slit adjusting mechanisms of some instruments.

Ease of Control or Adjustment.

The usual operational adjustments consist of racking the plateholder up or down to provide for exposure of several spectra on one plate and of changing the position of the prism or grating to expose the plate to a selected portion of the spectrum in instruments that produce spectra larger than the photographic plate. For the first of these adjustments a large clear scale or rotation counter should be provided. Controls should be easily accessible from the normal working position of the operator and should be as simple in operation as possible.

Commercial Instruments.

Medium Quartz Spectrograph—Bausch & Lomb Optical Co., Rochester, N. Y.

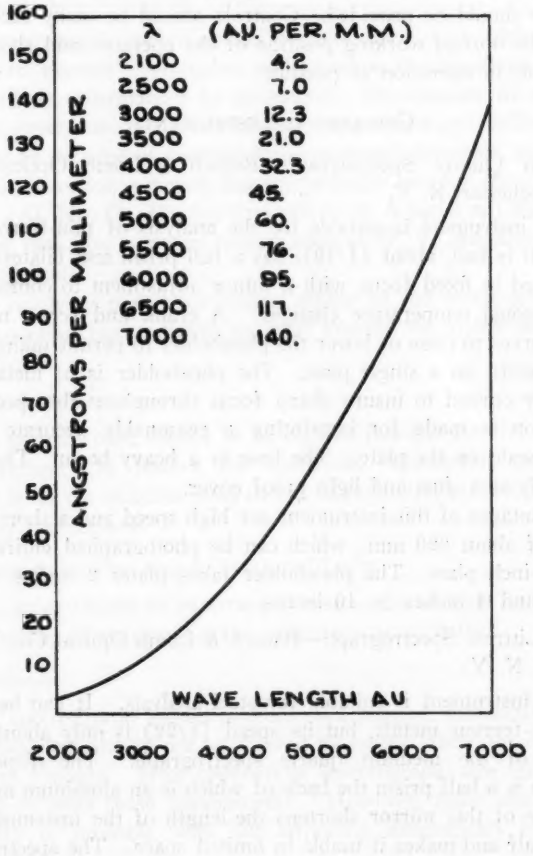
This instrument is suitable for the analysis of non-ferrous alloys. It is fast, about (f/10), has a full prism and bilateral slit. It is used in fixed focus with a minor adjustment to compensate for seasonal temperature changes. A crank and screw mechanism serves to raise or lower the plateholder to permit taking several spectra on a single plate. The plateholder is of metal and properly curved to insure sharp focus throughout the spectrum. Provision is made for imprinting a reasonably accurate wave length scale on the plate. The base is a heavy beam. The case acts only as a dust and light proof cover.

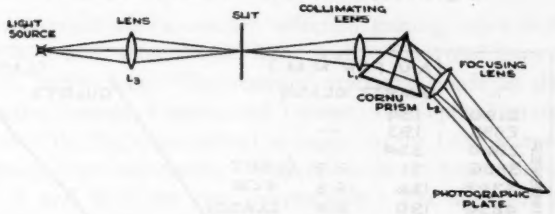
Advantages of this instrument are high speed and a short spectrum of about 220 mm., which can be photographed entirely on one 10-inch plate. The plateholder takes plates 2 inches $\times$ 10 inches and 4 inches $\times$ 10 inches.

Large Littrow Spectrograph—Bausch & Lomb Optical Co., Rochester, N. Y.

This instrument is suitable for steel analysis. It can be used for non-ferrous metals, but its speed (f/22) is only about one-fourth of the medium quartz spectrograph. The dispersing medium is a half prism the back of which is an aluminum mirror. The use of this mirror shortens the length of the instrument to about half and makes it usable in limited space. The spectrum is about 30 inches long requiring three exposures on a ten-inch

LINEAR DISPERSION OF BAUSCH & LOMB MEDIUM QUARTZ SPECTROGRAPH





OPTICAL DIAGRAM OF A MEDIUM SPECTROGRAPH

plate to record it completely. The focusing system includes a cam arrangement which allows ten portions of the spectrum to be centered on the plate.

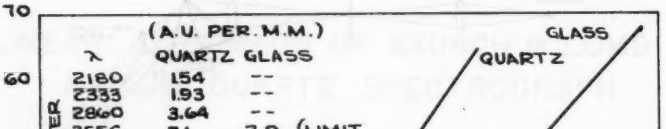
The arrangement allows the operator a rather wide selection of his spectrum regions. Adjustments are affected by a wheel and illuminated scale, controlled from the operator's normal working position. The plateholder head can be revolved about a central pivot to insure best focus of the spectrum. Other features such as plate-racking device, slit, etc., are similar to the medium quartz instrument. A weak quartz plano-convex lens immediately in front of the slit, acts as a field lens. Provision is made for imprinting a millimeter scale on the plate to act as a guide in locating lines in any given focal position.

A glass prism and carriage can be used in place of the quartz to produce a more dispersed spectrum in the visible or longer wave length end.

Hilger Co., Ltd., of London, England, also makes a large Littrow quartz spectrograph substantially similar to the one described above. The more modern of these has a continuous wave length adjustment.

Gaertner Scientific Company of Chicago, Illinois, makes a spectrograph, substantially similar to the Littrow type. Though a full prism is used, the length of the instrument is reduced by the use of an auxiliary mirror. It is claimed that fogging due to scattered light is considerably reduced in this instrument.

LINEAR DISPERSION OF BAUSCH & LOMB LITTROW TYPE SPECTROGRAPH



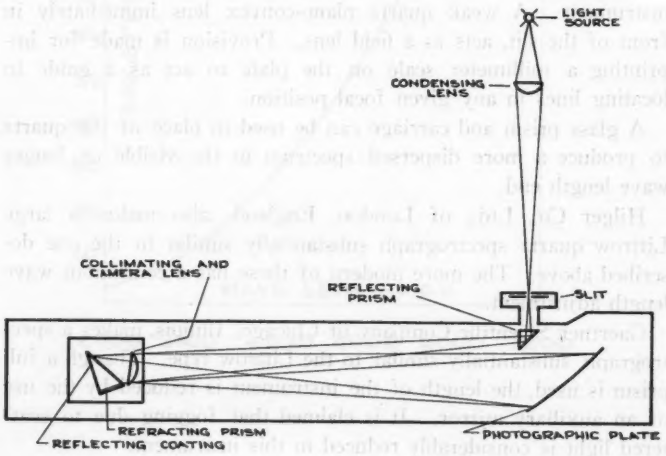


DIAGRAM OF THE OPTICAL SYSTEM OF A LITTROW TYPE SPECTROGRAPH

Grating Spectrograph—Baird Associates, Cambridge, Mass.

This instrument uses a concave reflection grating, ruled 15,000 lines per inch with about 50,000 lines in all. The ruled lines are about 1½ inches long. The concave grating is made in three focal lengths, 3 meter, 2 meter, and 1 meter. The optical arrangement (called the Eagle mounting) is similar to the Littrow mount for the prism type instruments. Dispersions in the first order are about 5, 7, and 15 A per mm., respectively. The apertures are f/30, f/20 and f/10, respectively. The controls including the shutter are all electrically operated by switches located on the front panel. Fixed slits are used, the standard widths being 25, 50, 100, and 200 microns, respectively.

The 3 m. instrument can be used for the most complex spectra, the dispersion in the 4th order being only about 1.3 A per mm. Ordinary thin plates, 4 inches × 10 inches, can be used in the larger instruments, but film must be used in the 1 meter grating because of the excessive curvature necessary to bring the entire plate into focus. Film can be used with the 3 m. spectrograph by using a film adapter. The large instrument is particularly useful where the longer wave portions of the spectrum must be employed.

Grating Spectrograph—H. W. Dietert Co., Detroit, Michigan—Applied Research Laboratories, Glendale, California.

This instrument uses a grating, 20,000 lines to the inch, the ruling being 2 inches wide and 1 inch high. Usually one position only can be used, that position of the spectrum, extending from 2300 A to about 4400 A. The dispersion is about 7 A per mm., which necessitates projection if steel analyses are to be made. Another position may be built into the instrument to extend the spectrum up to about 6600 A. An adjustable slit is used.

Densitometers.

The function of the densitometer is to measure the optical density of spectrum lines. This measurement consists of determining the relative amount of light transmitted through the line compared to the intensity of the original incident beam.

Commercial densitometers perform the measurement in different ways. The technical details of various instruments are fully described in the manufacturers' literature. The present discussion will be confined to the principle of densitometry in general and to some characteristics of the various available commercial instruments.

There are two general types of densitometers, the comparison type and the measuring type.

Comparison densitometers incorporate in their construction a strip of photographic plate upon which is imposed a density wedge which varies continuously in blackness from clear at one end to opaque at the other. This strip is mounted in a graduated slide. Provision is made to view the spectrum line through an eye piece containing a slit so arranged that the field contains part of the line and part of the wedge. By moving the wedge until the line appears to be of the same density as that of the portion of the image of the wedge in the field of vision, the reading on the scale on the wedge can be used as a measure of the spectrum line density. The principle is similar to that of the visual exposure meter used by photographers, with some refinements added. A modification of this scheme indicates equality of density by means of an electric eye. The light source of the comparison type densitometer need not be particularly constant as variations in light intensity affect both the comparison field and line equally. However, for precise use the blackness variation of the comparison field must be continuous.

In measuring densitometers a beam of light is thrown on a photo electric element, either a barrier layer cell or a photo electric tube. The electric output of a barrier layer cell when used is usually applied directly to a galvanometer whereas it is usual practice to amplify electrically the output of a photo electric tube and measure the amplified output by means of a galvanometer, micro-ammeter, potentiometer-bridge or other device. In any case the intensity is adjusted to give a constant deflection or indication on a scale. The light of the measuring beam is held constant and passed through the spectrum line onto the photo electric element and again measured. The decrease in electric output is used as the measure of the density of the spectrum line. It is theoreti-

cally possible to measure the intensity of both the unobstructed beam and of the light which passes through the line in absolute units by means of a vacuum thermopile or bolometer. However, at present no available commercial instruments employ such a device.

(*a*) Gaertner Microdensitometer—Gaertner Scientific Co., Chicago.

In this instrument, light from a mercury lamp is split into two beams, one of which is passed through the spectrum line and the other through a calibrated wedge constructed of photographic gelatin between two pieces of glass. The two beams are reunited in an eye piece, the spectrum line appearing as a narrow line in a small square field. The wedge is turned by means of a knob until the spectrum line is indistinguishable in the field.

The principal advantages of this instrument are its simplicity and freedom from mechanical or electrical parts "to get out of order". It is small, compact, and may be used on an ordinary desk. Densities as high as 2.5 can be measured.

Its sensitivity depends on the eye of the observer and measurement of many lines becomes tiring. Ordinarily the number of lines that may be consecutively read is about 30. The spectrum lines must be rather wide for the eye to detect the transmitted light through the line properly. This instrument is suitable where occasional determinations are to be made.

(*b*) Baird Densitometer—Baird Associates, Cambridge, Mass.

This instrument is of the comparison type. The image of the spectrum is projected onto a screen containing a slit. The line to be measured is centered over the slit. Behind the slit is a photo-electric tube. A second slit and photo-electric tube are moved over a density wedge illuminated by the same source. Equality of response of both tubes is indicated by an electric eye. Amplification of the photo-tube output is employed.

The measurements are not particularly rapid and so not suited to intensive use in high speed routine analysis. It is claimed that densities as high as 3.5 can be measured. This instrument requires wide spectrum lines such as made with a high dispersion spectro-

graph. Best results are obtained with spectra made on the grating spectrograph.

(*c*) Microdensitometer—Department of Engineering Research, University of Michigan, Ann Arbor, Mich. Hilger Co., Ltd., London, England.

In these instruments the image of the spectrum is projected onto a screen in which there is a slit. Behind this slit is a photoelectric (barrier layer) cell. The output of this cell is fed directly into a precision, short period, galvanometer equipped with mirror and scale. The ratio of the galvanometer deflection through the clear plate and through the line is used as a measure of the transparency of the line.

The time required to make a reading (dependent upon the period of the galvanometer) is reasonably short for these instruments. Using a 50 c.m. scale the density range is restricted to about 0.8. Because the deflection (through the line) is quite small above 0.8, the readings are not reliable.

The galvanometer must be hung on a support to suppress vibration. The room should be semi-dark. To obtain an optical lever sufficiently long to yield requisite sensitivity it is necessary to hang the galvanometer about 10 feet from the densitometer. Densitometers of this type are specially valuable where it is necessary to report analyses within as short an elapsed time as possible. An operator can use an instrument of this kind for several hours without becoming unduly fatigued.

Highly precise measurements may be made particularly for low density values. The spectrum line may be moved or swept across the slit which tends to maintain accuracy with speed. The instrument made by the University of Michigan has a device for projecting a comparison standard spectrum, whose lines may be marked, adjacent to the projection of the spectrum under measurement which expedites location of lines on the spectrum to be measured.

The quality of the optics used in the projection system is important since scattered light will vitiate the accuracy of the measurements.

Recording Micro Densitometer—Leeds and Northrup, Philadelphia, Pa.

The filament of a special lamp, fed by a power pack, is projected on to the spectrum plate, and thence onto a photo-electric tube. The output is amplified by a d-c amplifier, passed through a microphone chopper and again amplified. The amplified output is then compared with the voltage of a potentiometer circuit. Any unbalance affects either of two thyratron tubes which in turn actuates a motor to turn the potentiometer contact in the direction to restore the electric balance. The motor likewise moves a pen that draws a line on a moving strip chart. The recorder is the Leeds and Northrup Speedomax unit. The spectrum plate, and line, is moved across the filament image by a motor. Various controls such as amplification, bias, plate speed, chart speed, are included.

This type of densitometer is particularly useful in laboratories where results are to be reported in lots. Many similar spectra are recorded on one plate. The density of a certain line in all spectra may be quickly recorded merely by moving the plate up or down and throwing a switch on and off to start and stop the plate motor. While it is possible to read densities up to 2.2, precise results are limited to densities of 1.7. The manufacturer's specification gives a precision of 2 per cent, of full scale deflection as maximum deviation. Charts may be obtained with logarithmic ruling and thus enable densities and density differences to be obtained directly.

MISCELLANEOUS EQUIPMENT.

Miscellaneous equipment, such as specimen grinders, sector discs, hand viewing lenses, viewing boxes, and projectors, though minor items, are necessary for the proper functioning of a spectrographic laboratory. These units are available to suit the special needs of the particular purchaser. Reference should be made to the catalogues of the various optical manufacturers for special items.

However, a useful item manufactured by the Dietert Company, Detroit, Michigan, merits some consideration here. This unit is known as the "Calculating Board" and will be found useful in expediting calculations or "transpositions" of analytical results from the densitometer readings where many routine analyses of

one type are to be reported. The unit consists of a drawing board, a tee-square and a vertical member sliding in a groove in the tee-square. Using calibration curves in conjunction with scales attached to the tee-square, the vertical member and the groove, fast calculations can be made as with special slide rules.

CHAPTER VII.

Operations.

In this section will be discussed the modus operandi of spectrographic analysis itemized as follows:

(A) Qualitative Analysis and Identification of Lines.
(B) Preparation of Standards.
(C) Quantitative Analysis (Routine).

(A) QUALITATIVE ANALYSIS AND IDENTIFICATION OF LINES.

There must be known reference spectra before qualitative analyses can be expeditiously accomplished. In practice, it is customary for a laboratory to have a library of spectra of the materials usually encountered. For example, in the Industrial Test Laboratory there is a file of spectra of steels of all kinds, aluminum alloys, magnesium alloys, lead, tin, zinc, electrode coatings and so on. The characteristic lines of the important elements are marked on each plate. When an unknown material is received, its spectrum is compared directly with the material it resembles most closely and any outstanding or unsual lines determined. An experienced spectrographer can usually classify a spectrum for the predominating element almost at a glance. Determination of impurities or minor constituents is then made by comparison with standard marked plates or by wave length measurement.

It may be found of interest to discuss the methods of line identification. Line identity is established by means of wave length tables. These tables show, for the various elements, the corresponding spectrum lines of various wave lengths. Line identification then is reduced to the determination of the wave length of a certain line.

There are absolute means of determining wave length using interferometers, but there is no need of going to that extreme in

practical spectrography. The practical determination of wave length on a certain plate is that of interpolation. That is, the wave lengths of some lines nearby the desired line being known, the problem becomes that of deriving the wave length of the desired line from measurement of the linear intervals or distances between the known and unknown lines.

To establish known wave lengths reference is usually made to an iron spectrum, because it has many lines and can be easily reproduced. There are spectrum atlases or maps on the market that exhibit an enlarged iron spectrum with wave lengths indicated. An iron spectrum is made with the spectrograph to be used and the general pattern of the lines on the plate compared with the pattern on the map. Certain groupings are recognized and thus a few known lines are obtained. The manufacturer of any spectrograph will furnish plates of the iron spectrum with at least a few of the lines identified for wave length. Usually there are enough lines given, when used in conjunction with spectrum maps, to identify all the other iron lines by interpolation.

Another method that can be used to select the initial lines, when only the general regions of the spectrum are known, is to use the spectra of some elements the strong lines of which can be easily identified with the help of wave length tables. For example, information from the manufacturer indicates that a spectrum taken in position 5 on the Littrow spectrograph, an arbitrary focal number, extends from about 2500A to 3450A (1A = 1 angstrom unit of length = 10^{-10} meter). The spectrum of copper and silver are recorded on a plate adjacent to each other and to an iron spectrum. Reference to wave length tables indicates the following strong (black lines) at the following wave lengths:

Cu 3247.54, Cu 3273.96, Ag 3280.68 and Ag 3382.89.

The appearance of the 2 copper and 2 silver lines near the long wave end of the plate is unmistakable. The iron spectrum can thus be located in an atlas and some initial lines located. The identification of more lines is then accomplished by interpolation.

Interpolation of wave lengths will be discussed as it pertains to the various types of spectrographs.

1. Large Grating Spectrograph.

No wave length scale is practical for this instrument because the spectrum is longer than the length of practical plates. However, the spectra produced by gratings, within any 10 cm. length, is very closely normal, that is, the difference in wave length between two lines is proportional to the linear distance between those lines. For example, the proportionality constant for spectra taken with the Baird 3-meter grating spectrograph, in the first order, between 2500A and 3500A, is very close to 5.60. That means that a difference in location of a spectrum line of 1 mm. corresponds to a difference in wave length of 5.60A. The factor changes through the wave length scale and in the various orders, but the total change from about 2500A to 15,000A is only from 5.6 to about 5.0. It is then a simple matter to photograph the iron spectrum, identify a known line and then proceeding by steps of about 1 centimeter in length, to calculate the change in wave length. If clear sharp lines are selected at each step, and the wave length tables indicate no line other than iron nearby, minor corrections to the calculated wave length can be made. It is an easy matter to prepare iron spectra and indicate on the plate the wave lengths so determined. Such plates can then be used as guides or finding plates.

2. Large Littrow Spectrograph.

No wave length scale is practical because the spectrum is longer than the length of plates that are practical to use. A portion of the iron spectrum in which the wave length of a few lines have been determined is photographed.

The spectrum is not normal for any prism instrument. That is, the difference in wave length of two lines is not linearly proportional to the distance between them. This is due to the way in which the index of refraction of quartz changes with wave length. The dispersion curve, or interpolation curve approaches an hyperbole.

An empirical relation between the difference in wave lengths of two lines and the distance between them was discovered by Cornu in 1880 and modified by Hartmann in 1889. The Hartmann-Cornu formula is designed for spectrographs with one dispersing prism.

$$(n - n)\ (\lambda - \lambda_o) = c$$

where n = the linear measure of a line on the plate,

λ = the wave length of that line

n_o, λ_o, c = parameters to be determined for every plate.

Since there are three parameters, the wave lengths of three lines must be known in order to compute them. The computation is laborious if high accuracy is desired. An actual computation sheet as used in the Industrial Test Laboratory is shown in the figure. Once the constants have been determined for the given spectrum, the linear distances of a number of lines are measured and their wave lengths computed by the formula. These wave lengths are then corrected by use of the wave length tables.

HARTMANN-CORNU INTERPOLATION

$(\lambda-\lambda_o)(n-n_o)=C$

PLATE No. H-16

$\lambda_1 > \lambda_2 > \lambda_3$

$\Delta\bar{\lambda}_i = \lambda_2 - \lambda_3$

Σ_1 - 9106.56929

n_i	$\Delta\bar{\lambda}_i$	λ_i	n_i	$\Delta\bar{n}_i$
47576.11730	215.990	3286.755	220.270	69.070
-80787.80998	650.947	2851.798	123.340	146.000
23605.11639	434.957	2635.808	54.270	96.930

$\lambda_i n_i \Delta\bar{\lambda}_i$	$\lambda_i n_i$	$\lambda_i n_i \Delta\bar{n}_i$
15657 1040.58	723973.523385	5000 4851.03
-22896 4599.01	351740.76532	-5838 8967.82
6721 8554.55	143045.30016	18865 380.93

Σ_3 10375003.88 — Σ_2 -548126414

$\lambda_o = \frac{\Sigma_3}{\Sigma_1}$ 1139.287 — $n_o = \frac{-\Sigma_2}{\Sigma_1}$ 601.9072

$\lambda_i - \lambda_o$	$n_i - n_o$	c
- 2147.468	381.6372	- 819542.94
- 1712.511	478.5622	- 819543.04
- 1496.521	547.6372	- 819543.09

Such plates when prepared become permanent records or guides for wave length finding.

A more laborious method consists of proceeding step by step as in grating spectra discussed above, but making changes in the dispersion constant along the spectrum. The work is tedious and chances for error are great. An idea of the changes in dispersion,

angstroms per millimeter, for spectra prepared on the large Littrow spectrograph can be obtained from the following table:

Wave Length in Angstroms	*Angstroms per Millimeter*
2300	1.75
2800	3.34
3200	5.09
3400	6.23
3600	7.50
3800	8.84
4000	10.27
4200	11.80
4400	13.44

3. Medium Quartz Spectrograph.

This is a one position spectrograph and most instruments of this type are equipped with an internal wave length scale. This scale will serve for approximate wave length determinations; more accurate determinations should be made on a spectrograph of larger dispersion and the corresponding lines on the spectra of the medium quartz instrument determined by comparison of the patterns.

(B) PREPARATION OF STANDARDS.

The most accurate spectrographic results are obtained if standards approximate very closely in form and chemical composition the material to be analyzed. If it were practicable, it would be very advantageous to have standards for every type and composition of material. However, this is not feasible for a laboratory analyzing a large variety of materials.

If solution methods are used, it is a simple matter to prepare synthetic mixtures in all varieties of composition ranges. It is a difficult matter, however, to obtain a variety of steels representing the different types, by steps of slight variation in composition. For solid specimens, standards should be on hand containing not only maximum and minimum amounts of every element specified but also a few intermediate values. The various elements should also be arranged in combinations substantially like the specimens

to be analyzed. Thus, it is not advisable to prepare a number of graded steels containing equal amounts of Mn, Ni, Cu, Mo, V, Cr, Si, etc.

The experience of the Industrial Test Laboratory in using a number of aluminum alloys, prepared in the Laboratory, containing Mn, Si and Mg in equal amounts from 0.10 per cent to 2.0 per cent has shown that the accuracy of the resultant spectrographic analyses is much less than when type standards are used. A typical set of standards used for an aluminum alloy, Navy specification number 47A10d is listed below:

ALUMINUM ALLOY.

SPECIFICATION 47A10d.

	Specification	*Standards*		
		226	227	228
Cu	3.8 to 4.9%	4.06%	4.52%	5.05%
Mn	0.3 to 0.9	.38	.58	.84
Mg	1.2 to 1.8	1.21	1.48	1.60
Fe	0.5 Max.	.18	.22	.41
Si	0.5 Max.	.16	.20	.39
Cr	.25 Max.	.01	.07	.09
Zn	.03 Max.	.01	.02	.04
Other elements	.03 Max. each			
Total	.10			
Ni		.01	.02	.05
Bi		.01	.02	.04
Pb		.01	.02	.04

(c) DETAILS OF ROUTINE QUANTITATIVE ANALYSIS.

1. Preparation of sample.
2. Excitation and exposure.
3. Photography.
4. Densitometry.
5. Determination of percentage.

A general word of caution should be given about quantitative operations. Uniformity and standard procedure are of the utmost importance. All adjustments of results for differences in over-all

density, in plate calibration, in development, time and temperature, in size and shape of specimen, in constancy of source and so on should be looked upon as correction factors. If these factors, or corrections, become too great, there is an inevitable loss of accuracy. That is why so much stress is put upon such factors as constancy of excitation, of plate development, and of close similarity of specimen to standard. Only by rigorous control of uniformity, insured by establishment of simple, mechanical operations, can the highest accuracy and precision be achieved.

1. Preparation of Sample.

The only methods in which any attempt is made to compensate for non-homogeneity in the sample are those in which the sample is dissolved and an aliquot portion used. Methods in which a solid specimen is sparked, analyze only that portion of the surface embraced in a circle about ⅛ inch in diameter.

(*a*) Solution methods of preparation. Solution methods in general proceed in the following manner: A definite weight of sample is dissolved in an appropriate medium. The solution is cooled and adjusted to a definite volume. An aliquot, usually in the neighborhood of 0.1 to 0.2 ml. is dropped from a pipette into the cupped end of a purified graphite electrode, 2 inches long and 5/16 inch in diameter. The cup may be made by a drill about 3/16 inch to 1/4 inch diameter and the depth of the cup may vary from 1/8 inch to 1/4 inch. The electrodes are then dried in an oven for about one hour at 100 degrees to 105 degrees C. The graphite rods so prepared are used as the lower or anodic, electrode in an arc source, 220 v. d-c, the counter electrode being a graphite rod 5/16 to 1/8 inch in diameter.

If very low percentages of elements are sought, it is advisable to use specially purified electrodes such as made by the National Carbon Company. For ordinary work "Spectroscopic Carbons" made by the National Carbon Company will suffice. Spectroscopic carbons may be purified as described in the section on specific methods.

Typical methods of analysis using solutions are described in specific methods for zinc, lead and steel.

A variation of the procedure outlined above, using a spark

excitation instead of an arc, is described in the methods for steel analysis.

Solution methods have the advantage of uniformity and standardization of specimen shape and form. The disadvantages of solution methods are:

Time consumed in dissolving complex alloys and preparing electrodes.

A much more serious disadvantage is the loss of accuracy and precision in the determination of all but small percentages of constituents incident to the almost invariable use of d-c low voltage arc excitation. High accuracy and precision are, at present, not obtainable with solution, d-c arc methods. This method must be used occasionally by the Industrial Test Laboratory due to the difficulty of obtaining a specimen suitable for other treatment. The uses of solutions dried on electrodes and then excited in a spark source has not been investigated as fully as it probably deserves. Only one such method has been developed.

In closing the discussion on solution methods, one interesting though very special case should be mentioned. The analysis of caustic liquor for minute traces of impurities presents an almost impossible problem for conventional chemical methods. Using a drop of the caustic liquor on a flat graphite rod, similar to the second procedure described above, drying the solution and then using a high voltage a-c arc, Duffendack and Wolfe (Proc. of the Fifth Summer Conference on Spectroscopy, 1937; John Wiley & Sons, 1938) have obtained a remarkably precise and sensitive method. Their method analyzes caustic liquors for the following constituents:

Al_2O_3:	0.0001% to 0.014%
CaO	0.000054% to 0.005%
MgO	0.00006% to 0.0036%
SiO_2	0.001% to 0.10%
Cr	0.000075% to 0.01%
Cu	0.000016% to 0.005%
Fe	0.00001% to 0.01%
Mn	0.00001% to 0.00052%
Ni	0.000075% to 0.01%
Pb	0.00002% to 0.0034%

A tolerance of 5 per cent of the amount of constituent present is claimed. Since these analyses are made on one spectrum, with exposure of about one minute, the saving in time is apparent.

(*b*) Powder methods. About the only practical application of powdered specimens is in the analysis of minerals, pigments or other non-metallics. The powder is weighed, preferably on a semi-micro balance, for the amount is in the neighborhood of 2 to 50 milligrams and carefully brushed into a cupped graphite electrode. The cup should be made just deep enough to receive the volume of powder. This is then made the lower, or anodic, electrode of a low voltage d-c arc excitation source.

(*c*) Drillings. Drillings may be dissolved and treated as described under solution methods or may be compressed under an hydraulic jack or special press into pellets and held in a special jig. They are then treated as solid specimens in the form of small pencils. The Industrial Test Laboratory has, so far, developed methods only on the analysis of soft metals such as lead, zinc, tin, aluminum and storage battery actives, using this method of specimen preparation.

However, it is planned to investigate the extension of this method into the field of steel analysis. A high pressure pellet press is necessary. Often a binder, such as copper, is required to hold the steel grains together. This seems to be particularly necessary when hard steels are to be analyzed. The drillings must have definite size limitations. Because of the ready solution of the problem of uniform and standard specimen size and shape, this method may become very important. Reports on the accuracy and precision of analyses made on pellets compared to solid specimens are very favorable. There is at present a slight loss of reproducibility, but the increased tolerance of results may not be too serious. The additional time required to prepare such specimens, compared to the use of solid pieces, is not too great.

(*d*) Solid specimens. The Industrial Test Laboratory receives many solid samples of various shapes on which a flat surface must be ground for excitation. The minimum diameter of the ground surface is about 1 inch. This type specimen is used for aluminum analyses.

Many samples of sheet or plate are also received. These require little preparation.

Irregular specimens must be prepared by milling a flat spot on the surface and then dressing the milled area on a belt grinder in a manner similar to rough grinding metallographic specimens. For this purpose an emery or aloxite belt, 60 to 80 grit, has been found satisfactory. With these specimens it is necessary to use graphite counter electrodes which produce a gap of non-homogeneous nature thus resulting in some loss of sensitivity and an increase in fog on the plate which also reduces accuracy and precision. Until such time as standardized specimens can be received from Inspectors in the field, the laboratory must compromise the best accuracy in results for the sake of speed in reporting analyses.

Ideal spectrographic specimens are pencils, about 5/32 inch to 1/4 inch diameter and from 1 inch to 2 inches long. The ends are ground to a cone, or in some cases spherical. Two such pins or pencils are used as the electrodes. The gap is homogeneous and maximum stability and sensitivity for the given type of excitation source is possible. Such pins are readily made in the laboratory when analyzing low melting metals or alloys such as those of lead or tin. An ordinary laboratory burner is sufficient for this purpose. The vessel may be either a porcelain crucible or pyrex test tube. It is often advisable to melt the metals or alloy in a vacuum or in an inert atmosphere to avoid oxidation, particularly when detection of traces of impurities is important. The mold may be an ordinary steel split block. Steel, aluminum or magnesium alloys cannot be so readily prepared unless the samples are prepared at the furnace. In such cases the samples are poured from a small ladle into a chilled iron mold. The chilling prevents segregation and so enhances the homogeneity of the specimen.

For the detection of trace elements in copper, a method of high sensitivity and stability is required. A specimen in the form of a bead of about 0.25 to 0.5 gram is used. The bead is held in a shallow cupped graphite rod which is used as the lower (anodic) electrode. The counter electrode is of spectroscopically pure copper. Excitation used is a d-c low voltage arc. There is some selective volatization or distillation of elements from the

bead specimen tending to result in reduction of accuracy or precision of the analysis. This behavior, however, does not appear to be serious in the analysis of pure copper ingot.

2. Excitation and exposure.

(*a*) Excitation.

(1) Low voltage d-c arc.

The specimens are placed in the clamps or jaws of the electrode holders. The gap is adjusted for location on the optic axis and for separation by means of a simple gauge. The arc is usually struck by touching both electrodes simultaneously with a graphite rod. Unless unusually high current densities are used, the low voltage d-c arc weaves from side to side. The anodic "hot spot" swings slowly around the rim of the lower electrode and constant attention is required to keep the arc column focused on the slit of the spectrograph. This effect is considerably aggravated when a condensing lens is used to focus the image of the arc on the slit of the spectrograph. Carbon (as distinguished from graphite) electrodes produce a steadier arc, probably due to the difference in thermal conductivity. The arc can be steadied by using for the upper or counter electrode (i.e., the electrode which does not contain the material being analyzed), one of small diameter, about ⅛ inch. This results in increasing the current density and so acts to produce a steady discharge. For reproducibility, it is necessary to keep the current constant. A 220-volt source is much better in this respect than a 115-volt source. A variable rheostat (carbon pack) and ammeter provide the necessary controls.

Except for analysis of a few zinc specimens, the d-c arc is not used for quantitative work in the Industrial Test Laboratory. The tendency toward low accuracy and low reproducibility of d-c arc spectra may be ascribed to flickering and to the high heat generated, causing preferential or fractional distillation or boiling, some of which may be sub-surface. In solid specimens this tends to cause erratic quantitative results. However, the d-c arc is about the only available excitation source for use in qualitative analyses of trace impurities or quantitative analyses of minerals, some paint pigments, ash, welding electrode coatings, refractories or of such material as tungsten rod.

(2) High voltage condensed spark (a-c).

The electrical characteristics of the circuit, having been adjusted, the specimens are placed in the jaws of the electrode holder and the circuit completed by a starting switch or button. It is necessary to have the gap adjusted before the high potentials is applied. This is a simple mechanical operation accomplished by means of gauges, or fixed positions for electrode jaws. It is advantageous to time the exposure by an electrical timer (such as the one made by the Automatic Temperature Control Company of Philadelphia, Pennsylvania, Series 2805) rather than a stop watch. Best precision is attained with exposures of about 60 seconds.

(3) High voltage a-c arc.

The operation of this source is similar to that of the spark with one exception. A 2200 or 4400-volt arc will not strike across a 3 mm. gap unless it is initiated by a source that will ionize a path across the gap. The usual source of this spark is a Tesla coil. It may be timed to act just long enough to strike the arc.

(*b*) Exposure.

Because of the initial chemical changes due to heat during the sparking of a pair of solid electrodes or the erratic effect that may be due to any geometrical imperfections on the specimen, it is usual to allow the excitation to proceed for some 5 to 10 seconds (sometimes up to 30 or 45 seconds) before opening the shutter of the spectrograph to expose the photographic plate. This is termed the "pre-spark period". It is advantageous, for uniformity, to have the shutter action controlled by an electric timer.

Use of printed scales. The reading of spectra is facilitated if a scale is printed on the plate. Spectrographs with non-adjustable wave length range, such as the medium quartz may have an internal wave length scale, only approximately accurate. For variable position spectrographs, it is necessary to resort to an arbitrary scale ruled in millimeters. Such scales are not so important in laboratories where a large number of similar analyses are performed, for the operators soon learn to recognize the appearance of the spectra. When many types of materials are analyzed it is of considerable help to have such a guide.

Arrangement of work. If specimens are individually analyzed as they are received, it is a simple matter to keep track of the spectra, because they are analyzed practically in the order received. In analyzing lots of different materials the procedure at the Industrial Test Laboratory is as follows: Incoming samples are arranged by types, and in order of their analysis numbers. The various specimens of each type are then arranged in groups that are to be taken on one plate. As far as possible only like samples are recorded on one plate. Each plate is marked with a number in the dark room before putting it into the cassette or plateholder. The cassettes are identified by permanent numbers. A sheet is prepared, listing all specimens to be taken on a given plate, in the order they are to be exposed, and the plate number. As each specimen is used, the corresponding number on the sheet is checked off. The proper position of each specimen is thus checked. Standard envelopes for the plates are used with a form printed on them to expedite recording the analyses.

3. Photography..

The photographic or dark room procedure for treating the spectrographic plates is substantially similar to the ordinary methods used by an amateur photographer. There is one essential difference, namely, that all steps are carefully controlled.

Development is performed in trays, in which the solution is agitated. Mechanical rocking devices are very useful for this purpose. The temperature of the various solutions is carefully controlled and the time the plates are in the developer and fixing solutions is carefully timed. The usual sequence of operations is as follows: The plate is put into a tray containing enough developer (at the proper temperature) to cover the plate completely. The plate is then rocked by hand, or stroked with a camel's hair brush about 2 inches wide, or the entire tray rocked by a mechanical rocker. The time is controlled by an electrical dark room timer for long development times or by watching a luminescent, large, sweep second clock for periods under 1 minute.

When development is completed, the plate is lifted by the edges, dipped into clean running water and put into the fixer (or hardener and fixed, depending on whether one or two solutions

are used). When the plate is hardened and fixed, it is well washed, preferably in a rapid stream of cool water. The plate is then wiped with a clean sponge or cotton and dried. Eastman Spectrum Analysis No. 1 plates can be dried under an infra-red lamp or over a glow heater in a current of air. Other plates must be dried at room temperature. It is not advisable to use an alcohol rinse to dry plates, for that usually leaves a thin film or scum. The plate is then ready for reading.

4. Densitometry.

Frequently a satisfactory estimate of the amount of constituent present can be obtained by a visual comparison of the density of some selected lines. While this method is not of the highest precision, it is the most rapid and is used whenever it satisfies the accuracy requirements. If the visual method will not suffice, the density of selected lines is read on a densitometer. The operations involved depend on the type instrument used as outlined in specific procedures and in the foregoing references to densitometry. It is advisable to train operators to record or read the lines in a systematic manner to minimize errors.

Due care should be taken to note any imperfections that may be present in the plate such as smudges, scratches, pin holes, streaks, and the like. Such faults interfere with the proper reading of lines. Faulty plates should be discarded and the specimen re-exposed.

5. Determination of Percentage.

(*a*) *Visual comparison of lines in the same spectrum.* Whenever accuracy requirements will permit, this method is the fastest means of obtaining analytical estimates. The procedure is perhaps best illustrated by an example.

To determine the per cent of element A in the base, or matrix, B, by visual inspection:

Two lines of the spectrum of B, say B1 and B2 have been selected. They are of different density, B1 is blacker than B2. A selected line of A, say A1, is referred to. The spectrum having previously been investigated, it was determined that if the concentration of A is less, for example, than 0.01 per cent, A1 is lighter than B2. And, if the concentration of A is more than

0.10 per cent, A1 is darker than B1. Hence, if the density of A1 is between that of B2 and B1, it can be said that A is present in an amount between 0.01 per cent and 0.10 per cent. Whenever possible, a number of such line pairs are selected (see method for copper ingot). It may be possible (depending on the nature of the material and its spectrum) to make more extensive estimates in this manner. A selected pair of lines, of B and A, that are of visually equal density at a certain percentage of A, is called an equi-density line pair.

The method of equi-density line pairs is fast, if all other conditions can be controlled, reasonably precisely. It was one of the earliest methods used in spectrographic analysis. It is not always possible to find line pairs which will give requisite accuracy. There are no real criteria of uniformity of other conditions such as excitation, plate response, or development. Attempts have been made to establish such criteria. They are usually of the following nature. Two other lines of B, say B3 and B4, are selected and it is assumed that if these two lines are of equal density—" all other conditions " have been reproduced. It is difficult, as a rule, to find such lines and even more difficult to establish their sensitivity to important, though slight, changes in developer temperature, arc current, or plate response, etc. The theoretical reasons for such difficulties are elaborated in the section on the characteristic function of the photographic plate. As a rule, this method is useful only in the determination of small amounts or where the spectrum lines are not too dark to be evaluated by eye.

(*b*) ***Visual comparison with standards.*** This method is based on the direct comparison of the spectrum of the material being analyzed with the spectra of standards. In the analysis of a zinc alloy for magnesium in the range 0.03 per cent and 0.08 per cent, three zinc standards are used having magnesium contents of 0.03 per cent, 0.055 per cent and 0.08 per cent. The spectra of these standards are taken on the same plate as the specimen to be analyzed. Selected magnesium lines in the spectra of the samples are compared for density with the corresponding lines in the spectra of the standards and the magnesium content estimated.

This method is less precise than the method of equi-density line pairs, but is rapid. Its precision depends on "constancy of all other conditions". As a rule, it is useful only in the determination of small amounts or where the spectrum lines are not too dark to be evaluated by eye.

(*c*) *Method of total combustion.* A weighed portion of the material is excited in a d-c arc and the arc continued until all the material is consumed. The spectra so produced may then be compared visually with those of standards or the lines may be read on a densitometer and the determination of percentage obtained from working curves, taking into account the actual amount of the material used.

(*d*) *Method of calibrated plates and working curves.* This is the most modern method of analysis. It takes all known factors into account and when properly applied will yield the most accurate and precise results obtainable by spectrographic methods. Although the theoretical basis is a little involved, the actual operations are simple and mechanical.

The particular photographic emulsion is calibrated, that is, a curve is drawn correlating the stimulus and response of the photographic plate. (The theory is elaborated in the section on the characteristic function of the photographic plate.) A specific method for the preparation of such a curve is given in the section on the calibration of a photographic plate. The density or transparency reading of a line is used to obtain a relative log intensity value from such a curve. Working curves are then prepared, from standards, correlating the difference in log intensity of a spectrum line of the base material and a line of the element being analyzed, with the percentage of the element present.

In outline the operations are as follows:

Analysis of material B for element A.

Reference lines B1 and A1.

1. Measure density of B1 and A1.
2. From calibration curve obtain relative intensity of B1 (say I-B1) and relative intensity of A1 (say I-A1).
3. Subtract—(I-A1) from (I-B1).

4. Refer to working curve of element A. From value of (I-B1)—(I-A1) read per cent of A on curve.

The operations 2, 3, and 4 are frequently performed on mechanical devices, based on the nomograph or multiple slide rule principles, which are on the market.

CHAPTER VIII.

PHOTOGRAPHY.

Part I—The Chemistry of Image Production.

Section A—*Basic Theory.*

1—Chemistry of Development.
2—Chemistry of Fixation.
3—Chemistry of Washing.

Section B—*Preparation of Solutions.*

1—Note on Mixing Operations.
2—How to Mix Developing Solutions.
3—General Hints on Mixing Developers.
4—How to Prepare Fixing Solutions.
5—Cleaning Containers for Photographic Solutions.

Section C—*Use of Solutions.*

1—Using Solutions.
2—Useful Life of Developers.
3—Useful Life of Fixing Baths.
4—Effect of Temperature on Action of Solutions.
5—Importance of Rinsing.

Section D—*Plates and Their Development.*

1—Plates.
2—Development Process.
3—Variation of the Development Process.

Section E—*Some Troubles and Their Causes.*

Part II—The Physics of the Developed Image.

Section A—Measurement of the Photographic Spectrum.
Section B—Calibration of Photographic Plates.
Section C—The Characteristic Curve.
Section D—Example: Eastman Spectrum Analysis No. 1—Calibration of Emulsion.

Part I—The Chemistry of Image Production.

The photographic plate has certain definite advantages over other known devices that could be used as receivers of radiation. Among these advantages may be enumerated the following:

1—*Economy:* Plates are not expensive and many spectra may be put on one plate.

2—*Simplicity of Use:* Plates are commercially available in many types and sizes. The development procedures have been well studied and have been established in a sequence of simple operations.

3—*Multiple Record:* A plate records simultaneously the presence of a large number of wave lengths or bands. The actual number of spectrum lines is limited usually by the resolving power and linear dispersion of the spectrograph rather than the resolving power of the plate.

4—*Integrated Record:* The response of a plate is proportional to the *product* of the intensity of the incident radiation and the time of exposure. Hence, the effect of low intensities can be effectively amplified by longer time exposures. This property makes a plate a very useful receiver for low intensities.

5—*Permanent Record:* The advantages of a permanent record are obvious. A well prepared plate can be stored and referred to, even re-measured, for as long as a half year after the plate has been made.

The use of a photographic plate entails disadvantages, the most serious of which are:

1—*Selective Response:* The sensitivity and rate of response of a photographic plate is strongly dependent on the wave length of the incident radiation. Most emulsions respond well in the range of 2500 A to 4500 A. Radiation in the lower ultra-violet or upper red near infra-red requires special emulsions and treatment for its reception. Radiation in the regions of the far ultra-violet or deep infra-red cannot be recorded on photographic plates in a satisfactory manner.

2—*Non-linear Response:* The response of a photographic plate is not linearly related to the product of intensity of incident

radiation and time of exposure. This necessitates calibration of the photographic plates.

3—*Uncontrollable or Random Variability:* Plates of the same manufacturers lot number show variations in response that must not be neglected in precise work.

Nevertheless, it is difficult to foresee now what device will or could supplant the photographic plate, which is discussed as outlined below:

1—*The Chemistry of Image Production:* Development, fixing, washing, and drying.

2—*The Physics of the Developed Image:* The interpretation of a photographed spectrum considered as a record of spectrum intensities.

3—*Properties of Commercially Available Plates:*

Section A—Basic Theory.

1—The Chemistry of Development:

If a light sensitive material such as silver bromide, AgBr, is exposed for a short time to light, the material is changed. If the exposed material after exposure is placed in a proper chemical solution, termed the "developer", the following reaction takes place:

$$AgBr\ (\text{light struck}) + \text{Developer} \rightarrow Ag + Br$$

The free silver deposited is black and constitutes the image. This image is made up of grains, or a minute, coke-like mass of metallic silver, which remains in the same position as the bromide crystal from which it was formed.

The removal of the bromine from the AgBr is termed reduction. Not all reducing substances are suitable as developers. A reducing agent, to be used successfully as a photographic developer, must be able to reduce exposed silver bromide without affecting unexposed silver bromide. The speed of reaction of the reduction should also be controllable. Almost all developer formulae use only hydroquinone and monomethyl para-aminophenol sulphate (known under the trade names of ELON) (Eastman Kodak Co.) or METOL (Merck or Mallinckrodt Co.).

Hydroquinone and Elon have quite different characteristics as developers. An image developed with Elon comes up very quickly and gains density slowly, while the hydroquinone image comes up very slowly but gains density steadily and rapidly. Small changes in the temperature affect hydroquinone greatly and affect Elon very little. A small quantity of sodium bromide (NaBr) or potassium bromide (KBr) affects hydroquinone much more than it does Elon. These differences in the developing agents depend upon the chemical nature of the substances themselves and the particular property to which these differences are due is called the "reduction potential" of the developer.

The reduction potential alone does not determine the speed with which the developer develops the image, because this depends also, to a great extent, upon the rate at which the developer diffuses into the emulsion and on the quantity of developing agent and other substances in the developer. A high reduction potential enables a developer to continue to develop more nearly at a normal rate under adverse circumstances, such as at a low temperature or in the presence of bromides.

The addition of a bromide, such as NaBr or KBr, greatly retards development, and it is found that the higher the reduction potential of a developer the more bromide is required to produce a given retarding effect. Measured in this way, hydroquinone has a much lower reduction potential than Elon. In fact, hydroquinone has so low a potential that it is rarely used alone, but is generally used with Elon.

Most developing agents to develop at all must be in alkaline solution, and the energy depends upon the amount of alkali present. The developers of high reduction potential, which bring up the image very quickly, require less alkali than those of low reduction potential. Hydroquinone is often used with caustic alkali, while the other developing agents require only the weaker carbonated alkali.

If too much alkali is present the developer will tend to produce chemical fog (i. e., the unexposed emulsion will be affected) while if too little alkali is present it will be slow in action. Alkali also softens the gelatin of the emulsion and a too alkaline developer will produce over-swelling and will give trouble with frilling or blisters in warm weather.

The alkalies most commonly used in development are caustic soda, sodium carbonate, and Kodalk. In using sodium carbonate, the most commonly used one, care should be taken in preparation to allow for the water of crystallization in preparation of the developing bath. Thus different amounts of the decahydrate, Na_2CO_3. $10H_2O$, the monohydrate Na_2CO_3. H_2O, or the desiccated form, Na_2CO_3, are required to get the same alkalinity. The carbonated alkali has a tendency to cause blister formation within the gelatin layer as a result of the release of carbon dioxide (CO_2) when the alkaline developer is neutralized by the acid hardening fixing bath. This trouble is particularly serious in summer months when the temperature control of solutions becomes more difficult. Blister formation has been avoided entirly by using a new alkali, known as Kodalk, developed by the Kodak Research Laboratories. With increasing concentrations of alkali the activity of a developer does not change as rapidly with Kodalk as when carbonate is used. This is an advantage because it is possible, therefore, to control precisely the activity of a weakly alkaline developer by varying the concentration of Kodalk. Also the average potassium-alum acid fixing bath does not tend to form sludge with developers containing Kodalk as with developers containing carbonate.

Developers are necessarily substances which have a high affinity for oxygen and therefore developing solutions containing only the developing agent and alkali degenerate rapidly when exposed to air. The addition of sodium sulphite acts as a preservative by reducing the oxidation products of hydroquinone back to hydroquinone.

2. The Chemistry of Fixation:

After development the emulsion contains, in addition to the developed silver image, all of the unexposed and undeveloped grains of silver bromide, which will darken if exposed to light and obliterate the image. The emulsion is opaque, while a clear, transparent background is required. To make the image permanent, it is necessary to "fix" the negative by removing the unused silver salts without affecting the developed image. Only a few substances will dissolve silver bromide. Sodium thiosulphate,

$Na_2S_2O_3$. known to photographers as hyposulphite of soda or more usually as hypo, is generally used for this purpose.

In fixation, the silver bromide is dissolved in the hypo by combining with it to form soluble complex thiosulphates of silver and sodium. It is desirable that the fixing bath shall also be able to neutralize the alkaline developer solution contained in the developed negative to stop the development uniformly and quickly, which prevents uneven development, and also to avoid stains from colored material produced by oxidation of the developer which has accumulated in the bath.

To prevent the gelatin from swelling and softening in the wash water, a hardening agent, such as potassium alum or chrome alum, is usually added to the fixing bath. These agents require an acid solution. Acids, however, tend to decompose hypo, causing the solution to become milky because of the precipitation of sulphur.

$$H_2S_2O_3 \text{.....} H_2SO_3 + S$$
$$2H_2S_2O_3 \text{.....} H_2S + H_2S_3O_6$$
$$2H_2S_2O_3 \text{.....} H_2S_4O_5 + H_2O$$

The reaction of thiosulphuric acid to form sulphurous acid and sulphur is reversible. Consequently, the acid decomposition of hypo can be prevented, in large measure, if enough sulphite is present to drive the reaction the other way. Sulphite also helps to prevent the oxidation of developer carried over into it. Thus, the practical fixing bath usually contains in addition to the hypo, an acid to stop the development, sulphite to prevent decomposition of the hypo, and a hardening agent for the gelatin.

Developer which is carried over into the fixing bath is alkaline. Consequently, a sufficient quantity of acid is required in the fixing bath (which is to be used for any length of time) to prevent neutralization by the developer carried over. This neutralization causes precipitation of sludge of aluminum sulphite. A relatively large quantity of acid of high pH or low hydrogenion concentration is necessary. The most commonly used is acetic acid, the strength of which is 28 per cent obtained by diluting three parts of pure glacial acetic acid with eight parts of water.

The compound, sodium bisulphite, $NaHSO_3$, can be used but does not give quite as good a reserve of available acid in the

bath as acetic acid does. A satisfactory non-hardening acid fixing bath can be prepared, also, by adding sulphite and bisulphite to hypo. Another satisfactory non-hardening acid fixing bath can be prepared by adding ammonium chloride to hypo.

The commonest hardening agent is potassium alum, the alums having the property of tanning gelatin. Potassium chrome alum is another commonly used hardening agent.

With fixing baths containing acetic acid, potassium alum, sodium sulphite and hypo, the range of acidity throughout which satisfactory hardening is maintained is rather limited. When the acidity varies much above or below this range, the bath does not harden at all; and when too alkaline, a sludge of basic aluminum sulphite is precipitated, rendering the bath useless. If boric acid is added to a fixing bath of this type, however, the range of acidity over which good hardening exists is extended considerably, and the sludging tendency of the bath is greatly diminished.

Chrome alum is also useful as a hardening bath between developing and fixing. A saturated solution of chrome alum retains its hardening properties well, though with use, when developer is carried over by plates, the hardening properties of the bath fall off, owing to the presence of sodium sulphite in the developer. Formalin is sometimes suggested as a hardening agent in fixing baths for hot weather processing. It should be used only in alkaline or neutral solutions. Formalin often irritates the mucous membranes of the nose and throat and its use is objectionable on that account. The commercial solution contains 37 per cent of formaldehyde and has the property of hardening gelatin very powerfully. A 5 per cent solution renders the gelatin of a film insoluble in boiling water in less than a minute.

3—The Chemistry of Washing:

Negatives are washed to remove the chemicals of the fixing bath, not to wash out silver compounds. The rate of washing depends largely upon the rate of diffusion of the hypo out of the emulsion into the water, provided the water in contact with the emulsion is continuously removed. The solubility of a substance fixes the ratio of the substance which can go into solution,

not its rate. A salt will diffuse more rapidly in warm water than in cold; but when washing a photographic material, the diffusion must take place in gelatin, and the warmer the water in which the gelatin is placed, the more it swells. This swelling hinders diffusion in about the same proportion as the rise in temperature accelerates it, so that washing goes on at about the same rate at all ordinary temperatures. Gelatin is like a sponge; the effect of hardening it is to contract all the network of the sponge, but in so doing the gelatin as a whole is not contracted and there is no difference in the diffusion between gelatin, which has not been hardened and that which has been hardened, unless the gelatin has been dried after hardening. If an emulsion is thoroughly hardened in the fixing bath and then dried, it will not expand much when soaked again and consequently diffusion through it will be difficult. Before drying, the hardening does not affect diffusion and the materials which wash most quickly are those in the gelatin which has not been swollen in its treatment, either in development or fixation, but has been kept in a firm, solid condition.

An average emulsion, when washed directly under the faucet, will give up half its hypo in fifteen seconds; so that at the end of fifteen seconds half the hypo will be remaining in it; after thirty seconds, one-quarter; after forty-five seconds, one-eighth; after one minute, one-sixteenth; and so on. It will be seen that in a short time the quantity of hypo remaining will be infinitesimal. This, however, assumes that the emulsion is continually exposed to fresh water, which provision is the most important factor in arranging the washing of photographic material. Hence, the best way to wash photographic plates is in a frame under a rapid stream of water flowing down the emulsion side. Experimental measurements will tell when a particular arrangement will wash a specific type of emulsion in any specified time.

Section B—Preparation of Solutions.

1—Note on Mixing Operations:

Since most solutions are intended for use at ordinary temperatures (65 degrees to 70 degrees F.), if hot water is used for

dissolving, the solution must be cooled again if it is required for immediate use. When mixing, therefore, as a general rule, dissolve the chemical in as small a volume of warm water (about 125 degrees F.) as possible, cool and dilute with cold water. After diluting with water, thoroughly shake or stir. When mixing a solution in a tank, never put the dry chemicals into the tank, but dissolve by mixing in separate containers and filtering into the tank. In the case of dry salts, such as desiccated sodium carbonate and sodium sulphite, always add the chemical to the water, to prevent formation of insoluble cake. One of the advantages of Kodalk is that it does not cake when added to water, regardless of the manner in which it is poured in.

2—How to Mix Developing Solutions:

A developer usually contains four (4) ingredients as follows:

(*a*) The developing agent—Elon or Hydroquinone.

(*b*) The alkali—Carbonates or hydroxide of sodium.

(*c*) The preservative—Sulphites or bisulphites of sodium.

(*d*) The restrainer—Bromides or iodides of sodium or potassium.

A developing agent such as hydroquinone dissolved in water, will develop if at all, only very slowly. On adding a solution of an alkali such as sodium carbonate, the hydroquinone at once becomes a developer, but the rate of oxidation is increased to such an extent that the solution very rapidly turns dark brown. If a plate is developed in this solution, it becomes stained and fogged. If a little sodium bisulphite is added to the brown colored solution mentioned above, the brown color or stain is bleached out and a colorless solution is obtained. Therefore, if the preservative is first added to the developer, on adding the accelerator the solution should remain perfectly clear because the sulphite preserves or protects the developing agent from oxidation.

An exception to this rule should be observed with concentrated formulas containing the developing agent Elon, or a similar developing agent, in concentrated solution. This substance is readily soluble in warm water (about 125 degrees F.) and does not oxidize rapidly. If the sulphite is dissolved before the Elon,

a white precipitate often appears, especially, if the sulphite solution is concentrated. This precipitate forms because Elon is a combination of an insoluble base with an acid which renders it soluble. When the acid portion is neutralized by a weak alkali such as sodium sulphite, the insoluble base is precipitated. This Elon precipitate is soluble in an excess of water and also in a sodium carbonate solution with which the base forms a soluble sodium compound. Some direction sheets recommend that a portion of the sulphite be dissolved to prevent the oxidation of the Elon, then dissolve the Elon, and then the remainder of the sulphite. Many users add a little of the solid sulphite to the Elon when dissolving the latter. If the Elon is dissolved alone in water at a temperature not above 125 degrees F., and the sulphite dissolved immediately afterwards, little or no oxidation products will be formed and be present to produce chemical stain.

The alkali may be added in one of three ways:

(*a*) Dissolve the alkali separately and add to the cooled Elon-sulphite solution. There is danger with carbonate, however, of the Elon precipitating before the carbonate is added.

(*b*) Add the solid alkali to the Elon-sulphite solution, stirring thoroughly until dissolved.

(*c*) After dissolving the Elon, dissolve the sulphite and alkali together, cool and add to the Elon solution.

Bromides and iodides are added to a developer to compensate for any chemical fog produced by the developer, or inherent in the emulsion. It is immaterial at what stage they are added during the mixing.

As a general rule standard developers of formulas given by manufacturers of photographic materials, such as Eastman, are used in spectrographic work. The formulas for these developers are always accompanied by mixing directions. Best results are obtained if these directions are followed implicitly.

3—General Hints on Mixing Developers:

(*a*) *Water Temperature.*—Use water at 125 degrees F. or less except when a higher temperature is specifically recommended.

(*b*) *Containers.*—Use good enameled glass, or hard rubber. Avoid tin, copper, or galvanized iron which cause fog.

(*c*) *Water first.*—Pour water into the container, and then add the chemicals. Caking results from adding water to dry chemicals. Boiling water should never be used unless specifically recommended.

(*d*) *Avoid Premature Oxidation.*—Add a little sulphite to the water before adding the developing agents.

(*e*) *Complete Solution of Each Chemical.*—Dissolve each chemical completely before adding the next, and in the order given in the published formula.

(*f*) *Check the Formulas.*—Arrange the chemicals needed for mixing at one end of a shelf or bench. As each one is weighed out, place the stock can or bottle on the opposite side of the shelf or bench. Use only chemicals of reliable manufacture.

4—How to Prepare Fixing Solutions:

Fixing baths may be divided into the following classes:

(*a*) Plain hypo solutions.

(*b*) Acid fixing solutions consisting of hypo with the addition of sodium bisulphite or sodium sulphite with acid.

(*c*) Acid hardening fixing solutions.

When mixing a plain hypo solution it may become cloudy on dissolving the hypo in which case it should be filtered before using.

All acid fixing baths contain either sodium bisulphite, or a mixture of sodium sulphite and a weak acid. The directions are as follows:

(*a*) Add the bisulphite or acid sulphite solutions only to cold hypo solution or the hypo will turn milky.

(*b*) An acid hypo solution gradually becomes milky, therefor a stock solution of the sodium bisulphite or acid should be kept and added to the plain hypo stock solution as required.

Acid hardening fixing baths are prepared by adding to hypo an acid hardening solution which contains the following ingredients:

(*a*) An acid such as acetic, boric, citric, lactic, maleic, malic, sulphuric, tartaric, which stops development.

(*b*) A hardening agent such as potassium alum or potassium chrome alum.

(*c*) A preservative such as sodium sulphite or sodium bisulphite. The latter acts as a preservative in two ways: It prevents the formation of sulphur and prevents the developer carried over into the fixing bath from oxidizing and turning brown.

It is usual to prepare an acid hardening solution as a separate stock solution and add this to the hypo solution as required.

The order of mixing is important, as follows:

(*a*) When mixing in one vessel, first dissolve the sulphite in warm water (about 125 degrees F.), then add the acid and then the potassium alum. The alum dissolves more readily in the acid-sulphite solution.

(*b*) Another method is to dissolve the alum and sulphite in separate solutions, cool, add the acid to the sulphite solution and then add the alum solution.

(*c*) The hypo should be cool and dissolved completely before adding the cool hardener; otherwise sulphur is likely to be precipitated.

(*d*) If the order of mixing is reversed and the alum added first to the sulphite a white sludge of aluminum sulphite is formed which dissolves with difficulty when the acid is added. Therefore, if after mixing, the hardener is milky and a sludge settles out it is due to a relative insufficiency of acid, that is, the acid used was either not up to strength or too much sulphite was added. Potassium alum fixing baths containing boric acid have the least tendency to sludge of any baths of this type.

(*e*) With other hardening baths the order of mixing is usually the same.

5—Cleaning Containers for Photographic Solutions:

Apparatus used for mixing and containing photographic chemicals becomes discolored and sometimes coated with decomposition products of the solution. It is advisable to clean all containers each time they are emptied. Most cleaning solutions are either strongly alkali or acid and should be used with discretion. The most common tray cleaner is an acid solution of potassium bichromate made by dissolving potassium bichromate in water and adding concentrated sulphuric acid. This solution will remove stains caused by oxidation products of developers, silver

stains and some dye stains, and is a very useful cleaning agent. When an acid fixing bath sulphurizes, the colloidal sulphur is quite difficult to remove with a cleaning agent, but the addition of glass beads or sand to the bottle or vessel and shaking will be found effective.

Enameled trays which have been used with strongly alkaline developers or caustic solutions, rapidly lose their glossy surface and become roughened and discolor easily. If such containers are used with dye solutions, the dye is taken up in the pores of the enamel, and is very difficult to remove. Trays badly discolored should be discarded.

Section C—Use of Solutions.

1—Note on Using Solutions:

Photographic solutions, especially developers, vary considerably in their period of usefulness. This "useful life" as it is sometimes called, is, an important property of a solution and should be studied by everyone handling photographic materials. Many factors influence the useful life of a solution, such as whether it is used intermittently or continuously, the extent to which the surface is exposed to the air, the temperature, the nature and reactions of the chemical constituents, and the manipulative procedure used in handling plates in the bath.

Usually the photographic solution is discarded when its working rate is too low to be practical. Methods of reviving developers are somewhat vague. For spectrographic work it is highly inadvisable to push solutions to their extreme useful life. Developers should be discarded after being used once or as soon as staining begins to appear, no matter how slight.

2—Useful Life of Developer:

Without Use. A freshly mixed developer (prepared with water boiled to free it from dissolved air) stored in a completely filled and stoppered or wax-corked bottle, will keep indefinitely even in the light. Under ordinary conditions of storage, the bottle or vessel contains more or less air. An ordinary cork or non-airtight cover continually exposes the surface of the developer to contact with the air, which oxidizes both the develop-

ing agent and the sodium sulphite present. This results in the lowering of the developing power in direct proportion to the amount of oxidation of the developing agent, the action being accelerated by the oxidation of the preservative or sodium sulphite. The oxidation products of developing agents are usually colored so that the developer on keeping frequently turns brown. In the presence of sodium sulphite, however, the oxidation products of hydroquinone may be colorless. The fact that an old Elon-hydroquinone developer is colorless is, therefore, no indication that the original developing power is unimpaired. An oxidized Elon or Elon-hydroquinone developer frequently fluoresces strongly.

With Use. During development, several reactions are taking place:

(*a*) The developing agent and the sulphite are being oxidized by the air.

(*b*) The developing agent is being destroyed as a result of performing useful work in reducing the exposed silver halide emulsion to metallic silver.

(*c*) Oxidation products of the developer and the by-products, sodium bromide and sodium iodide, are accumulating. The bromide and the iodide and the developer oxidation products restrain development while the oxidation products prevent aerial fog. The restraining action of the bromide and the iodide is analogous to cutting down the exposure, so that with an old developer it is not possible even on prolonged development to get the ultimate desired results.

3—Useful Life of Fixing Baths:

A satisfactory acid hardening fixing bath should have certain properties, namely, a fairly rapid rate of fixation, good hardening, a long anti-sludging life, and a long "useful" life. The time for fixation is usually twice the time for the milkiness or opalescence of the unreduced silver salts to disappear. This depends on the strength of the hypo (30 per cent to 40 per cent fixes most readily), the photographic material, the temperature of the solution (65 degrees F. is recommended), and the degree of exhaustion of the solution.

The hardening properties are influenced by a large number of factors. A certain minimum quantity of alum is required to give the necessary hardening, while an excess of alum may produce too much hardening and induce brittleness. Normal fixing baths such as Formula F-5 are compounded carefully to give hardening at 180 degrees to 200 degrees F. This is determined by immersing a strip of the fixed and washed plate in water, heating the water slowly until the gelatin flows away from the glass. Ordinary spectrographic plates should be completely fixed in less than five minutes in a fresh bath. Chrome alum fixing baths lose their hardening properties, however, as developer is carried into the bath because of the resulting increase in sulphite concentration. A good fixing bath should not sludge during its useful life when used at 65 degrees to 70 degrees F. The changes in temperature of the fixing bath effect the rate of fixation and the useful life of the solution. It is dangerous practice to allow the temperature of the bath to rise much above 75 degrees F. as the solution is apt to precipitate sulphur.

A fixing bath should be discarded when the time to clear the plate has increased to twice as long as the time required to clear in a fresh bath. By clearing is meant the disappearance of the white film of unused silver halides. If the bath for any reason shows any tendency to stain the plates or to sludge, it should be discarded.

4—Effect of Temperature on Action of Solutions:

Nearly all chemicals used in photographic work have a high enough melting point so that there is little danger of the solids melting while stored in bottles or other containers, but it is good practice to keep storage bottles cool and dry. When in solution the effect of temperature on chemicals is much greater and must be taken into account with every photographic solution. Under normal working conditions, a temperature of 65 degrees F. is recommended for development.

The temperature coefficient of development varies with the developing agent, being least with the developers of high reduction potential, such as Elon, and most with developers of low

reduction potential, such as hydroquinone. Thus the behavior of a mixed hydroquinone developer depends upon the temperature. At low temperature the hydroquinone is inert, while the rate of Elon is not effected to the same extent. At high temperatures the activity of hydroquinone increases far more than the Elon. If development is continued for a sufficient time, all developers will fog, but the fog reaction is a different one from that of development, and apparently has a different temperature coefficient, one which is much higher than the temperature coefficient of the development reaction itself. Consequently, a developer which will develop a material to a good density with low fog at a normal temperature, may produce very bad fog if the temperature is high. It is of paramount importance that fixation always be carried out at a normal temperature (65 degrees to 70 degrees F.). Fixing baths frequently decompose very rapidly with liberation of free sulphur if kept for some time at the temperature of 95 degrees F. Although the rate of fixation is increased at higher temperatures, it is very bad practice to allow the temperature of a fixing bath to rise above 75 degrees F. in any case.

About the best general rule for temperature is to mix, store, and use the solutions at a temperature recommended in the manufacturer's instructions.

In addition, care must be taken to preserve a uniformity of temperature of the various solutions. The gelatin, the substance of the base carrying the silver halides belongs to a class of substances which are called colloids. When a gelatin jelly is dried, it shrinks and forms a horny layer, smooth and rather brittle. This dry gelatin when placed in water will at once absorb the water and swell again to form a jelly. A small quantity of either an acid or alkali will produce a considerable increase in the swelling and since the developer is alkaline and the fixing bath is acid, both these solutions have a great tendency to swell the gelatin, especially, when they are warm. Thus all solutions should be kept at the same temperature in order to avoid sudden contractions or expansions of the gelatin which may result in loosening the film from its support or in the production or coarse wrinkling of the film.

5—Importance of Rinsing:

It is important to thoroughly rinse plates after development and before fixing. When a plate is transferred from the developer directly to the fixing bath, the alkali in the developer retained by the emulsion neutralizes some of the acid of the fixing bath. The addition of developer also gradually destroys the hardening properties of the fixing bath. This is particularly true when a chrome hardener solution is used as an intermediate between the developer and the fixing solutions. A scum composed of chromium hydroxide is produced by the reaction between the chrome alum and the alkaline developer carried over on the emulsion, this scum does not form in a fresh bath if the film is well agitated on immersion. When the bath becomes old, a scum will tend to form even if the plates are agitated, and the bath should then be discarded. Plates should always be wiped with wetted cotton or a cellulose sponge after washing to remove any possible traces of scum because once the emulsion is dried, it is impossible to remove the scum.

Section D—Plates and Their Development.

1—Plates:

Non-color sensitive plates have very limited sensitivity to light other than blue and the near ultra violet. The Process emulsion Eastman 33 or Eastman Spectrum Analysis No. 1 are emulsions of this type. Orthochromatic, commonly called Ortho Plates, embody some additional sensitivity to the spectrum. By the addition of certain dyes to the emulsion this sensitivity extends into the yellow-green. Practically all such emulsions have the word "ortho" incorporated in the name used. Panchromatic plates are sensitive to all the spectrum up to the near infra-red. When the occasion demands the use of plates specially sensitized to a particular region of the spectrum, reference to the Eastman Kodak Company's "Photographic Plates For Use in Spectroscopy and Astronomy" will be found helpful. This booklet contains the necessary charts to enable the choice of a proper type of sensitization. Information about more specialized plates can be obtained by writing to the Eastman Research Laboratories at Rochester, New York.

2—The Development Process:

In the preceding sections, the nature and characteristics of the chemicals used in the various photographic processes were discussed. These chemicals behave differently under different conditions, but always according to the same pattern. Photographic processes in spectrographic work are subject to objective quantitative measurements rather than to visual or pictorial evaluation. Therefore, various conditions such as temperature, concentration, time of action, stirring, and so on, must be carefully controlled in order to obtain the desired uniformity and reliability of results.

All developing solutions are said to have four essential ingredients or functions. In some formulas two of these may be present in one chemical, but the resulting solution acts as if all parts were present in conventional form. These four parts or functions are:

(*a*) Reducing agent.
(*b*) Preservative.
(*c*) Accelerator.
(*d*) Restrainer.

(*a*) *Reducing Agent.* Elon, Metol, or Pictol are some trade names for a very popular reducing agent: Monomethylparaaminophenol sulphate. Elon works at the same rate of speed in all parts of the emulsion, from the area of least exposure to the area of most exposure. Hence Elon builds density first and contrast afterward, as it is not sensitive to the action of the restrainer. Its speed is very little affected by changes in temperature. It is non-staining in its action unless used in an old or exhausted solution which has been exposed to the air for some time. Elon is not generally used alone but usually in combination with hydroquinone.

Hydroquinone works on the areas of highest exposure, and does not begin on the less exposed areas until the heavily exposed areas are almost completed. Hence we say that hydroquinone builds contrast first, and density afterward. It is quite sensitive to action of the restrainer. It is extremely sensitive to changes in temperature. At 50 degrees F. it will not work at all and at 90 degrees F. it will work on the unexposed salt as well as the

exposed part. Hence it will "fog" any film when the temperature is 90 degrees F. or above. No other reducing agent is so sensitive to temperature as is hydroquinone. It is also non-staining in its action unless used in an old or oxidized solution. A combination of Elon and Hydroquinone is a very fine solution for most photographic purposes. There are several other reducing agents not so generally used but which give excellent results. Study of them may be found interesting by the individual worker on his own initiative particularly in connection with the present discussion.

(*b*) *Preservative.* This chemical should be one which has a great affinity for oxygen. Several of the sulphites are used for this purpose, the most generally used one being Sodium Sulphite. There is a great deal of oxygen in the water used to mix the solutions and if left there, it oxidizes a large part of the reducing agent and produces stains before the necessary developing of the silver image is completed. By the addition of a sufficient quantity of preservative, practically all the free oxygen will be removed from the solution, the work of developing the image will be completed as planned, and no stains will result from the over-oxidizing of the reducing agent.

(*c*) *Accelerator.* Any of the alkalies can be used as an accelerator. The one most generally used is Sodium Carbonate. Without the use of this ingredient the reducing agent works slowly or not at all. The action of the accelerator is a double one. It first causes the gelatin of the emulsion to swell and permit the solution to permeate quickly throughout the layer. Then as the silver salt is reduced to silver, the alkali reacts with a liberated halogen.

(*d*) *Restrainer.* There is no chemical known which will supply just the right amount of increase in the speed of developing, so it is necessary to use an alkali and then add some restrainer to control the action. Some of the bromides and iodides can be used for this purpose. The most generally used restrainer is Potassium Bromide. The addition of bromide controls the action of the developer and prevents the veiling over or fogging effect produced by too energetic action of the reducing agent which develops some of the unexposed salt also.

The ideal developing solution is one which will develop all the light exposed grains of silver salt in the emulsion and have no effect on any that are not exposed. When all the exposed grains have been developed, the action should stop, even though the plate is left in the solution indefinitely. However, there is no such solution known. As the amount of exposed salt is decreased by being reduced to silver, the action of the solution will slow down, but before it has reached a complete stop, it will begin to act on the unexposed salt. So the plate must be removed from the solution just before this point is reached, in order to avoid "chemical fog" in the resulting negative.

The formulas given by manufacturers for various developing or other solutions have been tested fully, and if used as directed, will produce the indicated results.

Bearing in mind the nature of the quantitative results desired for spectrographic purposes, once a set of conditions for development of the plates has been decided upon, it should be strictly adhered to.

3—Variation of the Development Process.

Everything up to this point has been based on the normal action on plates. In order to overcome some abnormal conditions or to obtain some especially desired results there are three major variants which can be used. These may be used singly or in combination as outlined below. Taking them in the order of their usual frequency of use, they are:

(a) Variation of Time and Temperature.
(*b*) Variations of Concentrations of Solutions.
(c) Variations by Modification of Formula.

(*a*) The changes brought about by variation of time and temperature have been discussed in preceding sections.

(*b*) Variations of concentration of the solutions will have a proportional effect upon the resulting action. If the solution is diluted with an equal volume of water, the time required to complete the action will be nearly doubled. If only half the required water is added, the action will be completed in about half the time. There are limitations however to these latter two generalizations as there will be found a point where the chemical will not go into

solution. Also too great a dilution will slow down the action to a point where the gelatin will soften and melt away before the developing is completed. However the change in time is directly proportional to the amount of change in the normal volume of solution within a range of dilution or concentration of about 100 per cent. This variation in the concentration of the formula can be used to good advantage in hot weather to shorten the time of developing so that the swelling of the film will not be so great and for speed work where every minute counts. As a general rule a more concentrated solution will give greater contrast than the normal concentration, and less contrast will result with dilution below normal concentration.

(*c*) Modification of Formula. Variations in developing procedure are made to produce specific desired results. The discussion in the section on the physics of the developed image, sets forth what is desired in a photograph of a spectrum and how those desired properties are effected by changes in development procedures.

Section E—Some Troubles and Their Causes.

1—Temperature Troubles:

If the room temperature is too high abnormal swelling of the gelatin layers, before hardening in the hardening bath, may result. If the film becomes swollen, subsequent hardening will not reduce the swelling and may cause it to become reticulated. Even when reticulation does not occur, the rate of drying is materially decreased. The difficulties encountered when working at high temperatures are fog, softening of the gelatin, pin-holes and reticulation of the film. As previously stated the developer, rinse bath, fixing bath and wash water should be kept at the same temperature. For special developer formulas that may be used at temperatures above 80 degrees F., it will be found helpful to refer to the "Eastman Book of Formulas" and directions therein given followed exactly.

2—Developer Troubles:

(*a*) *Fog.* Fog is the name given to the effect produced by the developing of portions of the silver salts which are not part of

the image. This "graying" of the image may be general, covering the whole film or it may be local, appearing in one or two parts of the film. Fog is sometimes chemical fog, and is caused by faulty mixing of solutions. It may result from mixing in wrong order, mixing at too high a temperature, leaving out the restrainer, adding too much accelerator, the use of impure reagents or some combination of these. It manifests itself by a gray deposit which is evenly spread over the entire plate including the clear margins. If it occurs before the normal length of time for developing, the solution must be discarded and the new one mixed carefully. Stray light reaching the film will also cause a fog which may be local or general but the appearance of the plate will generally indicate the focal point of the fog at these points next to the opening permitting the stray light to strike the plate.

(*b*) *Dichroic Fog.* Appears as a yellowish or reddish green metallic sheen when the film is examined by reflected light or as a pinkish tint when examined by transmitted light. Because of this dual character it is called dichroic or two-colored fog. This fog is formed in the developer or in the fixing bath. Some of the factors which contribute to its formation in a developing solution are the presence of sulphide and silver solvent or a prolonged immersion in a used developer.

(*c*) *The solution is colored.* As a general rule the developer is colorless or nearly so when mixed. If it is colored very much, it is likely to produce fog. The color may be due to impurities or improper mixing.

3—Fixing Bath Troubles:

(*a*) *Sludging of the Fixing Bath.* A fixing bath occasionally turns milky soon after the hardener is added and sometimes after being in use for a short time. This milkiness may be of two kinds.

(1) If the precipitate is pale yellow and settles very slowly on standing it consists of sulphur and may be caused by either too much acid in the hardener, too little sulphite or impure sulphite, or too high a temperature. (The hardener should be added to the hypo only when both are at room temperature.) An acid

fixing bath at 85 degrees F., will not remain clear longer than a few days, even when mixed correctly. Unless the bath is clear it is advisable to discard it. If a sulphurized bath is used, the sulphur is apt to penetrate the gelatin and cause fading of the image.

(2) If the precipitate is white and the gelatinous sludge settles on standing, it may be caused by either too little acid in the hardener or too little hardener in the fixing bath. As previously stated, when a relatively large proportion of the developer is carried over into the fixing bath, it soon neutralizes the acid in the hardener constituents and increases the tendency for precipitation of a sludge of aluminum sulphite. This action may occur as the bath becomes exhausted even though mixed correctly.

It is extremely important to use only the acid specified and to be sure of its strength because trouble is caused if more or less acid is used than is called for in the formula used. It has been found that the hardening properties of an aluminum acid fixing bath bear a relation to its tendency to precipitate aluminum sulphite. A bath containing an excess of acid and which may be used for a relatively long time before aluminum sulphite precipitates, does not harden as well as a bath which precipitates when a much smaller volume of developer is added.

(*b*) *The Bath Does Not Harden Satisfactorily.* This may result either from the use of inferior alum or not enough alum or the presence of too much acid or sulphite. On varying the proportions of acid, alum and sulphite in the fixing bath, it has been found that the hardening increases as the quantity of alum increases. Using a given quantity of alum and increasing the quantity of acetic acid increases the hardening up to a maximum, after which the hardening decreases to a point where it does not harden at all; boric acid behaves similarly. Hence, the need for closely following directions in making up the bath.

(*c*) When the sodium carbonate in a developer is neutralized by the acid in the fixing bath, carbon dioxide gas, if formed, produces tiny blisters in the emulsion if the gelatin is too soft to withstand the disruptive action of the gas. If the fixing bath contains an excess of acid and the films are not rinsed sufficiently, or if a strongly acid rinse bath is used, blisters are apt to be

formed. Blisters are more likely to occur in hot weather, especially when the bath is not hardening sufficiently. Blisters may be avoided by using KODALK as the alkali in the developer, because this chemical does not react with the acid to liberate gas.

(*d*) *Dichroic Fog.* If the fixing bath does not contain acid, or if it is old and exhausted and contains an excess of dissolved silver salts, dichroic fog may be produced.

NOTE: For spectrographic work, it is highly undesirable to attempt the removal of stains or fog by intensifiers or reducers. The action of such reagents affects the quantitative relations that are sought.

4—Negative Defects and Stains:

(*a*) *Abrasion Marks and Fingerprints.* Careful handling of the plates, touching only the edges is the only safeguard.

(*b*) *Air Bells or Bubbles.* The appearance of air bells on the plate during developing will be a round, clear spots with sharply defined edges. They can be prevented from forming by immersing the films in the solutions in the proper manner and keeping them moving correctly after immersion. Almost all of the other difficulties such as spots, cuts and scratches, drying marks are due to improper or rough handling of the plates. Any stain or defect in a spectrographic plate should be enough cause for its rejection. The exact cause of such a stain or defect can usually be found by careful analysis of the treatment to which the plate was subjected.

PART II—THE PHYSICS OF THE DEVELOPED IMAGE.

SECTION A—MEASUREMENT OF THE PHOTOGRAPHIC SPECTRUM.

The significant properties of a spectrum line as it appears on a developed photographic plate are (1) its width and (2) its blackness. Since the lines are geometric images of the slit, they should all be essentially equally wide, neglecting some minor variations due to the effect of slit width on spectrol purity. However, any real spectrum shows marked variation in line width. These differences are due to the turbidity of the emulsion. The gelatin silver bromide film is not transparent and hence it scatters or diffuses light or radiation falling upon it. Scattered light

is weaker than the incident beam. If the original beam is relatively weak, the scattered light will not record on the emulsion and the line appears narrow and sharp. However, if the incident beam is intense, the scattered light will be strong enough to affect the emulsion adjacent to the line image, producing a wider image on the plate than does a weaker beam. This phenomenon is known as halation. Thus, measurements of line widths and correlations with spectrum intensities are difficult to establish on an accurate or precise basis.

Therefore the blackness of a line instead of its width is used to estimate the intensity of the incident radiation.

Measurements made by the various photometers or densitometers are based on measuring the relative diminution or decrease of intensity of a beam of light due to its passage through the spectrum line. The intensity of a narrow beam of light in the densitometer is measured and held constant. The beam is then passed through the desired spectrum line and the intensity of the transmitted beam is measured. The intensity of the transmitted beam is less than that of the original incident beam striking the plate and the relative diminution in intensity is considered a measure of the blackness of the spectrum line. The exact procedures and means used to make this comparison vary with the type of densitometer used. Certain fundamental concepts and terms are commonly used by all workers in the field. The most common of these terms are defined below.

Let I_o = the intensity of the incident beam.

I_1 = the intensity of the transmitted beam.

Then I_1/I_o = the transparency, T, of the line.

I_o/I_1 = the opacity, O, of the line.

$\log_{10} O = -\log T$ = the Density, D, of the line.

($\log_{10}$ means the logarithm to base 10; i.e., the common or Briggsian logarithm.)

In the following the physical terms "transparency" or "density" (optical density) will be used in referring to measurements of photographed spectrum lines rather than terms such as "blackening".

As has been stated the response of a photographic material which has been exposed to radiation depends (1) on the wave length of the radiation and (2) on the intensity of the radiation. Photographic materials can be used for measurement of radiation in absolute terms only after having been calibrated by some form of non-selective type of receiver such as a thermopile or bolometer.

A non-selective receiver responds in a manner independent of the wave length of the incident radiation. That is, N units of energy at, say, 5000 A, and N units of energy at 2500 A will elicit the same response from the receiver. This is not true for photographic material, as may be shown by a very simple spectrographic experiment. In a spectrum of sodium on a Process plate, the line Na 3302.3 A is very dense while the line Na 5889.9 A is very weak, if present at all. Nevertheless the intensity of Na 5889.9 A is fifteen times that of Na 3302.3 A. Therefore, the photographic emulsion has a high variability with respect to color sensitivity, or, in other words, the densities or the transparencies of two spectrum lines are not measures of the true relative intensities of the two frequencies in the radiation emitted by the source if the lines are of widely different wave lengths.

The photographic emulsion is also non-linear in response to monochromatic radiation (i.e., radiation of one wave length), with regards to time and intensity of exposure. Everything else being kept constant, neither the transparency nor the density of a line is proportional to the time of exposure. In like manner neither the transparency nor the density of a line is proportional to the intensity of the incident light. By proportional is meant linear proportionality.

A series of exposures are made on one plate, keeping all factors constant except time of exposure. If the density of a selected spectrum line in the different exposures is measured and the values plotted against the time (or log time) of the corresponding exposure, in general, the curve will not be a straight line. Repeating the experiment keeping the time of each exposure constant but varying the effective intensity of the source (say by varying the distance of the source from the slit), and again measuring the density of a selected line in all the spectra and plotting these

values against the affective intensities (or log intensities), in general, the resulting curve will not be a straight line.

Thus no simple function of the response of a given photographic emulsion has been found which is linear with respect to wave length, time of exposure or intensity of incident radiation. Since, in spectrographic work, the relative intensities of lines in the source are sought by measuring their densities or transparencies on a developed plate, in order to obtain reliable and precise values, we have to consider and control variations of response due to the following factors:

(1) Development process.

(2) Type of emulsion, and for each emulsion:

(a) variation from batch to batch.

(b) variation from plate to plate in the same batch.

(c) variation over different portion of the same plate.

(3) Time of exposure.

(4) Intensity of the source.

(5) Wave length of the portion of the spectrum considered.

A spectrographic laboratory, particularly one engaged in routine analysis must be aware of the necessity of exposing and developing plates in an absolutely uniform manner and of limiting the spectrum used to one narrow range. It is further necessary to devise a method of interpreting density-differences to obtain reproducible accuracy and constancy of results. Such a method has been developed and is known as the "method of calibrated plates."

Section B—Calibration of Photographic Plates.

In calibrating photographic plates, the original density readings are corrected to compensate for change in the sensitivity or response of the plate due to:

(1) Variability of the response of different emulsions.

(2) Variability of the response of different batches of the same emulsion.

(3) Variability of the response of the plates due to the fact that the lines being compared are of different wave length and intensity.

The theory of plate calibration is simple. A number of spectra, usually made simultaneously, are recorded under known differences of conditions. A line is measured in those modulated spectra and a curve is drawn connecting the density or transparency with the variable condition. The foregoing discussed the effect of variable intensity of the incident radiation for a fixed time and of the effect of exposing a plate to a source of fixed intensity for a variable time. Another term should be defined, the *EXPOSURE* (symbol E) of a plate.

The *EXPOSURE* is defined as the product of the intensity into the time.

Under proper conditions, this is the significant factor. Exposure = intensity $\times$ time ($E = It$).

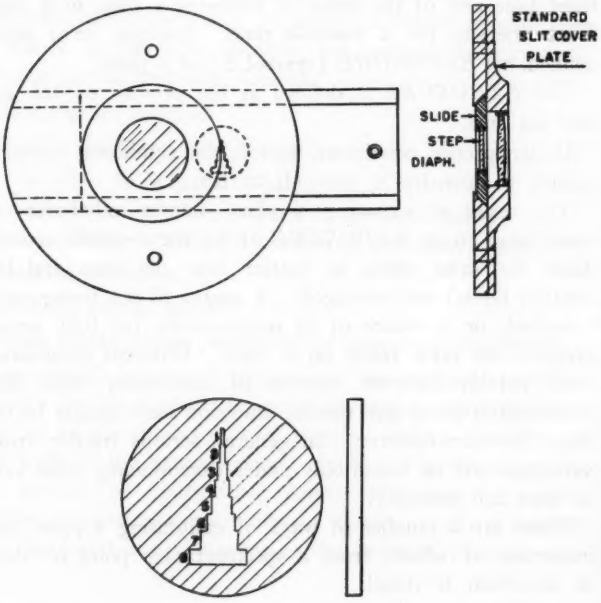
The result of exposing a plate, (under otherwise constant conditions) to an *EXPOSURE* of 0.1 meter-candle-seconds produces the same effect no matter how the time and intensity (within limits) are arranged. A source of 0.1 meter-candle for 1 second, or a source of 10 meter-candle for 0.01 second will produce the same result on a plate. Different emulsions, however, exhibit different degrees of conformity with this rule. Information about any specific emulsion may usually be obtained from the manufacturer. In general, serious trouble from such variations will be found only under exceptionally wide variations of time and intensity.

There are a number of ways of calibrating a plate, the most important of which, from a spectrographic point of view, will be described in detail.

1—Method of the Stepped Slit.

The slit is opened its full length and width. In front of the slit is placed a diaphragm, containing a slit with a series of stepped openings of known widths. (Figure 1) Within limits, the intensity of radiation transmitted through the sections is directly proportional to the width of the sectional slit. Thus contiguous spectra of known relative overall intensity are obtained. A source of continuous radiation must be used for illumination, in order that the radiation striking the plate may be proportional to the width of the slit in each step. As stated in Chapter III

the continuous source produces spectra of continuous wave length. By measuring the density of an (imaginary) line perpendicular to the dispersion of such a spectrum and plotting the readings against the width of the slit or slit factor a calibration curve is obtained by connecting the points with a smooth curve.



SKETCH of STEPPED SLIT and DIAPHRAGM MOUNT

FIGURE 1.

Preparation of the stepped slit requires great care, especially the narrower portions whose width should be in the neighborhood of 10 microns. A further disadvantage is the difficulty of obtaining a suitable source of continuous radiation in the ultra-violet region commonly employed for spectrographic analysis. The

source must have a fairly uniform intensity over the whole wave-length region of interest since the spectral purity of the image is a function of the slit widths in the various steps, and in a region of abrupt change of intensity, (as at the edge of a sharp spectrum line) the image given by the widest step will be affected to a greater extent than the image from the narrower steps. The stepped slit will function properly only if the slits are of such widths that denser lines are obtained on increased exposure not simply wider lines. It is therefore imperative, that a source of continuous radiation be used.

2—Method of the Neutral Step Weakener.

A neutral weakener, made by sputtering a quartz plate with some reflecting or absorbing medium (such as aluminum) in steps of known relative transmission is placed before the slit. Either continuous or monochromatic radiation may be used. This is theoretically the soundest method, but such a weakener is very difficult to prepare (and calibrate) with the absorbing layers in any kind of regular progression and to insure the neutrality of the layer, i. e., to insure a uniform absorption for all wave lengths.

3—Method of the Stepped Sector.

A rotating sector with stepped openings of known relative values is placed before the slit, which is opened to its full length and uniformly illuminated from top to bottom. The spectrum thus obtained has steps of known relative exposure times. A source giving either continuous or monochromatic radiation may be used for illumination.

Care must be taken to insure the uniformity of illumination of the slit from top to bottom. This may be checked by exposing the full slit of the spectrograph without the sector and then measuring the density on any given line from top to bottom.

Recently the step-sector method has grown in favor since it has been shown that the intermittency failures disappear when illumination is made by intermittent exposures of high enough interruption frequency. The intermittency effect (i. e., failure of the plate to integrate correctly short time exposures) becomes very small if the frequency of interruption is sufficiently high.

Intermittent time scale exposure variation, which the step sector method really is, becomes identical with an intensity-scale exposure, such as the step weakener. Therefore, a step sector may be safely used as a means of calibrating a plate provided the total radiation intensity is not too great nor the ratio of exposure time between two adjacent steps too excessive and the interruption frequency is high enough.

4—Method of Constant Source.

If reasonable assurance can be had that a source will give a spectrum whose lines are of a constant intensity distribution, and, which can be reproduced from time to time as needed, then that source can be used to calibrate a plate. The ideal spectrum would be that of the base metal or matrix of the material that is being analyzed. For example, when analyzing aluminum alloys it would be very convenient if some source emitting aluminum lines could be found that would consistently emit those aluminum lines in a constant intensity distribution. Measurement of the densities would then give the necessary data for calibrating the plate. The base metal spectrum would have to be analyzed for the intensity distribution of its lines by some of the previously described methods, or, the constant source may be used to obtain successive spectra of known exposure time, that is, spectra similar to those obtained with a step sector except that the components would be obtained successively rather than simultaneously. This would allow greater flexibility in use as well as do away with the troublesome task of insuring uniform slit illumination.

The Industrial Test Laboratory is investigating the use of high intensity gaseous discharge tubes of helium and argon as sources of spectra of sufficiently constant intensity distribution.

Construction of the Calibration Curve.

As is apparent from the above descriptions, all methods for calibrating plates are based on exposures with a known modulation or change in E (exposure). Due to inherent variability of the usual spectrographic sources, it is better technique to make the various exposures simultaneously so that whatever fluctua-

tions affect one step or spectrum will affect the others in like manner. For example, consider method 3, the method of the stepped sector. If the sector has 6 steps of ratio 2:1, 6 contiguous spectra, the ratio of exposure time of each spectrum to its neighbor being 2:1 are obtained. Assuming the validity of the relation E = It, if the spectra are made successively, not simultaneously, then it is absolutely necessary to insure the constant intensity of the source. If exposures, say, of 2, 4, 8, 16, 32, 64 seconds are made in succession and calibrating of the plate is attempted by measuring the density of the same line (real if a line spectrum or imaginary if a continuous source spectrum) then, if the source is not constant in intensity during the six exposures, the whole determination is valueless. That is the reason the six calibration spectra should be produced simultaneously.

Having obtained the calibrating spectra, say in method 3, measurement is made of the density of the same line in the various spectra. For example:

Using a sector disc of 8 steps, with ratio 2, record the reading, as follows:

Step	1	2	3	4	5	6	7	8
Log relative time	0	.3	.6	.9	1.2	1.5	1.8	2.1
Density	.07	.16	.40	.88	1.46	1.90	2.25	2.35

The log relative time ($= \log_{10} 2 = 0.3$) is proportional to the log E. Plot the values of log E on the X-axis and density on the Y axis. The resultant curve is known as the calibration curve, and expressed in the units given above is the well known H & D curve (i. e., Hurter and Driffield curve named after the two Englishmen who first used it as a plate calibration).

A little consideration will show how the calibration, or characteristic or H & D curve may be constructed by use of the other methods.

In the method (1) using the stepped slit, the density of an imaginary line perpendicular to the direction of dispersion is plotted against the slit widths, or against log of the relative width or against slit factor. In the method (2) using the neutral weakener, the relative transmission or log relative transmission

is plotted against the density of a line in the various steps. In the method (4) using a spectrum with lines of definite intensity distribution, the densities of the lines are plotted against the predetermined relative intensity of the various selected lines.

A study of the above methods will show that no correction is made, or even attempted, for the variation in exposure of a plate to radiation of different wave lengths. Any general correction of that nature is impractical. If it is necessary to work in different portions of the spectrum, measurements should be made to determine whether the response of the plate is significantly different to the various wave lengths used. If it is, then a series of characteristic curves will have to be prepared.

The characteristic curve is so important that it will be discussed in detail in the next section.

SECTION C—THE CHARACTERISTIC CURVE.

The principles underlying the construction of the characteristic curve are repeated. Simultaneous spectra are made in that portion of the spectrum in which interested, by using either (1) a step sector disc, (2) a step weakener, (3) a stepped slit, or (4) a constant source. In any one of the first three methods the Exposures (E) of the adjacent spectra are varied by changing the time (t) with the step sector, or the intensity (I) with the step weakener or stepped slit. If a constant light source is available successive exposures for unknown times can be made instead of making many exposures simultaneously. No matter what method is used the principle is the same.

A number of spectra that differ in a known manner either in time (t) or in intensity (I) of exposure, must first be obtained taking precaution that there is no known variation in intensity (I). Then measure the density (D) or transparency (T) of one line in all the modulated spectra. Then plot these measured densities (D) against the known various Exposures (E). In actual practice log E is usually used as one coordinate (the abscissa or X-axis) rather than E. The curve so obtained is known as the characteristic curve for the given emulsion at the particular wave length of the line that was used.

In the method using the stepped sector, while the relative time of exposure is known, the intensity is not known. However, spectrographic analytic work is always concerned with the relative intensity of two lines, never with the *absolute* intensity of either. Thus $\log E = \log I + \log t$. Consider two portions a and b of the same line as produced through different steps. Then, $\log E_a - \log E_b = (\log I_a - \log I_b) + (t_a - \log t_b)$. Then since the group of spectra obtained by the use of a stepped sector are excited and recorded simultaneously, and the readings are made on the same line, $I_a = I_b$. This is evident when it is considered that a rotating disc before the slit of the spectrograph cannot have any effect on the intensity of any radiation emitted from the source.

Consequently, $\log I_a - \log I_b$ is zero and $\log E_a - \log E_b = \log t_a - \log t_b$. Hence while log t is actually plotted as the X-coordinate, the difference of log t for two different portions of a line is equal to the difference of log E for these portions.

Consider 2 lines in a spectrum under analysis, line 1 and line 2. All parts of the spectrum on the plate were necessarily exposed simultaneously, i.e., $t_1 = t_2$.

Hence, $\log t_1 - \log t_2 = O$ and $\log E_1 - \log E_2 = \log I_1 - \log I_2$. Thus, the difference of *intensity* of two lines can be determined if the plate is calibrated by varying the *time* of exposure. While the absolute intensity of any line in a spectrum is not known the relative intensity, or difference of intensity, between any two lines in that spectrum can be determined.

To return to the curve. If density is plotted on the vertical or Y-axis against log E on the horizontal or X-axis, a curve shown in the accompanying Figure (Figure 2), is obtained. Using the coordinates as indicated, the curve is known as the H & D curve for the emulsion, after Hurter and Driffield, who first studied it. It is not necessary to use the coordinates as given. For example, either transparency or opacity or any function of them could be used as a measure of plate response for the Y-axis and E or any function of E as a measure of the excitation. However, density (D) and log exposure ($\log E = \log I + \log t$) are generally used for the following reasons: (1) the scales on both axes are comparable in range for usual

work, (2) the true or absolute log E coordinates are determined within an additive constant, or the absolute D $\times$ log E curve may be obtained by shifting the given curve either to the right or left on the horizontal axis *without distorting its shape*. If t had been plotted as the horizontal coordinate, instead of log t, the true exposure would be a multiple of the values obtained,

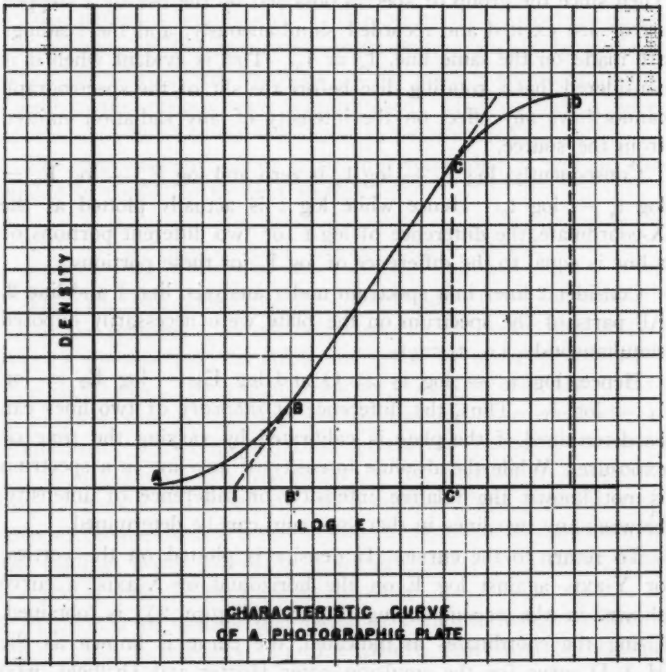


FIGURE 2.

E = It, and the transformation would result in an expansion or contraction of the X-axis. (3) The use of density, rather than any other function of plate response is arbitrary. (4) By using the D $\times$ log E coordinates a straight line is obtained for a considerable portion of the characteristic curve. This is a great help in actual plotting.

Consider the curve, Figure 2, ABCD. The curve proper, is divided into 3 parts; the toe AB (or region of under exposure), the shoulder CD (or region of over exposure) and the rectilinear portion BC (or region of correct exposure). In most emulsions BC is practically a straight line, hence the term linear portion. The intersection of the linear portion and the log E axis (1) is called the inertia point. The projection of BC on the log E axis is the latitude. The angle BC makes with the log E axis is called alpha. The tangent of that angle or the slope of BC, is one of the important parameters of the emulsion. It is called gamma (λ) or the *contrast factor*. The two factors, latitude and especially gamma, are of utmost importance for spectrographic use. Gamma is the rate at which density changes with respect to log E. That is, on the linear portion of the curve, the difference in density between two lines is equal to gamma times the difference in log E, or log I of those two lines;

$$\text{or } \triangle D = \lambda. \triangle \log I.$$

Hence gamma is a sensitivity factor. Since the whole practice of spectrographic analysis depends on the assumption of an increasing intensity in radiation of a line due to an alloying constituent with an increasing concentration of that element (i.e., an increasing difference in intensity between the line due to the minor constituent and a line due to the matrix or basic constituent), it can be seen that the higher the gamma of a developed photographic plate, the more sensitive that plate would be to detect such changes in composition. It should be noted that the higher the value of gamma, for a given maximum measureable density, the smaller the latitude, that is, the smaller the range of composition that can be handled by the spectrographic method. In actual practice, a compromise must be made. A lower gamma, in general, means a greater latitude; or, that a wider range concentration, in percentage, of the given element can be determined in a less-precise manner. A higher gamma, accompanied by a smaller latitude, means a more accurate determination, although in a smaller range. It is considered advisable to use as high a gamma as is practicable.

SECTION D—EXAMPLE—CALIBRATION OF AN EMULSION.

Plate—Eastman spectrum Analysis No. 1.

Method—Step-sector disc, 8 steps.

—Ratio 1.25; log ratio 0.10.

Table 1 contains the density measurements on a pair of lines near the indicated (nominal) wave length. The method of plotting a calibration curve using more than one line developed in Section B, using a step sector, is outlined as follows:

The readings on the segments of one line are plotted against the relative exposure time with the usual arrangement of coordinates. The vertical or Y-axis, or ordinate, is the coordinate of density (D) increasing upwards. On the horizontal or X-axis, or abscissa, is the coordinate of log E (= log t), increasing to the right. The origin of coordinates on the E axis is arbitrary. After the points corresponding to one line are plotted, the second line is entered on the curve with the segment which over-laps the first line, and the remaining points corresponding to the second line are plotted using the same log t interval. For instance, consider curve "B", the first line is plotted using the following coordinates:

Line 1

Step	*D Coordinate*	*Log E coordinate (arbitrary origin)*
8	1.22	0.80
7	0.95	0.70
6	0.68	0.60
5	0.46	0.50
4	0.29	0.40
3	0.17	0.30
2	0.10	0.20
1		0.10

The interval, or difference in coordinates between the steps on the log E axis, is the log ratio of the step sector.

We then find the log E value corresponding to the D value of 0.81, i.e., the reading on a segment of the second line included in the range of the first, for example, step 1 on line 2 is between

steps 6 and 7 on line 1. Referring to the Figure 3 for curve B we see that the log E coordinate corresponding to D = 0.81 is 0.65. Hence we plot the steps of the second line as follows:

Line 2		
Step	*D coordinate*	*Log E coordinate (origin no longer arbitrary) but determined from line 1)*
8		
7		
6		
5		
4	1.62	0.95
3	1.35	0.85
2	1.08	0.75
1	0.81	0.65

The interval, or difference in coordinates, between the steps on the log E axis, for line 2, is the same for line 1, that is, the log ratio of the step sector.

The curves obtained from Table I which follows are illustrated in Figure 3. For emphasis, it is repeated that the relative horizontal location of these curves is arbitrary. We have not determined the relative sensitivity, or "speed", as the term is used by photographers, of the emulsion at the various wave lengths. This cannot be done unless a source is available whose emission characteristics are known in absolute units. Hence, in general, no correction for difference of plate response due to differences in wave length of the incident light can be made. Care must be taken, therefore, in ordinary spectrographic procedure to use lines that are close together in wave length, that is, so close that there is a negligible difference in the shape of the calibration curves for their wave lengths. Table 2 exhibits the values of gamma for different wave lengths, a curve showing this relationship, obtained from table 2, is shown in Figure 4. This curve, as may be expected, has a considerable variation in shape depending on the type of emulsion used. Unfortunately, curves similar to the one shown in Figure 2 are not available for other emulsions, even from the manufacturers.

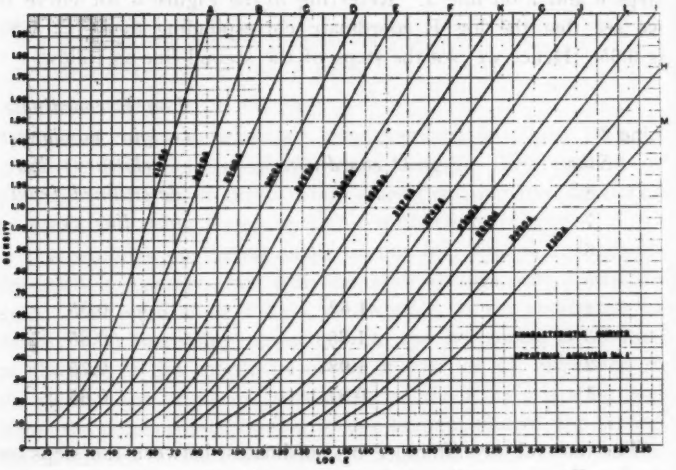


FIGURE 3.

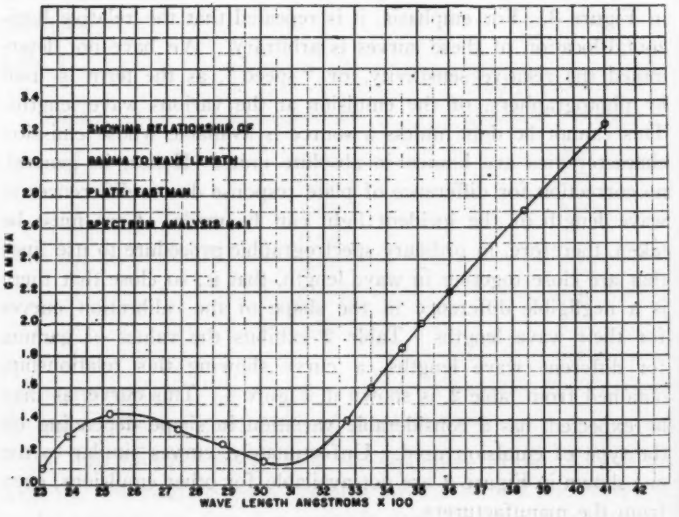


FIGURE 4.

TABLE I.

DENSITY MEASUREMENTS FOR STEP SECTOR CALIBRATION

STEP RATIO = 1.25; LOG RATIO = 0.10.

		A			B			C			D			E		
		4100 A			3840 A			3600 A			3510 A			3450		
	log	line	line		line	line		line	line		line	line		line	line	
step	E	1	2		1	2		1	2		1	2		1	2	
8	0.70	1.49			1.22			1.10			0.90			1.02		
7	0.60	1.17			0.95			0.88			0.70			0.83		
6	0.50	0.84			0.68			0.66			0.53	1.60		0.65	1.65	
5	0.40	0.55			0.46			0.47	1.66		0.38	1.40		0.48	1.47	
4	0.30	0.34	1.65		0.29	1.62		0.31	1.44		0.25	1.20		0.34	1.29	
3	0.20	0.20	1.33		0.17	1.35		0.19	1.21		0.15	1.00		0.21	1.10	
2	0.10	0.11	1.01		0.10	1.08		0.11	0.99			0.80		0.14	0.92	
1	0.00		0.69			0.81			0.77			0.61			0.74	

		F			G			H			I			J		
		3350 A			3270 A			3010 A			2880 A			2740 A		
	log	line	line		line	line		line	line		line	line		line	line	
step	E	1	2		1	2		1	2		1	2		1	2	
8	0.70	0.88			0.81	1.62		1.60	1.23		0.78	1.47		0.75	1.51	
7	0.60	0.72	1.60		0.58	1.48		1.48	1.12		0.65	1.34		0.62	1.37	
6	0.50	0.56	1.44		0.46	1.34		0.38	1.00		0.53	1.22		0.50	1.23	
5	0.40	0.42	1.28		0.35	1.20		0.29	0.80		0.42	1.09		0.39	1.10	
4	0.30	0.30	1.12		0.26	1.06		0.21	0.77		0.32	0.97		0.28	0.96	
3	0.20	0.20	0.96		0.18	0.92		0.15	0.65		0.23	0.84		0.20	0.82	
2	0.10	0.12	0.80		0.12	0.78			0.54		0.16	0.72		0.14	0.69	
1	0.00		0.64			0.64			0.43		0.10	0.59		0.10	0.56	

		K			L			M		
		2520 A			2390 A			2310 A		
	log	line	line		line	line		line	line	
step	E	1	2		1	2		1	2	
8	0.70	0.80			0.66	1.38		0.60	1.21	
7	0.60	0.66	1.60		0.54	1.25		0.50	1.10	
6	0.50	0.52	1.45		0.43	1.12		0.40	0.99	
5	0.40	0.41	1.31		0.33	0.99		0.33	0.88	
4	0.30	0.30	1.16		0.25	0.86		0.25	0.77	
3	0.20	0.21	1.02		0.17	0.73		0.18	0.66	
2	0.10	0.13	0.87		0.12	0.60		0.13	0.55	
1	0.00		0.73			0.48		0.10	0.45	

However, once such curves as those shown in Figures 3 and 4 have been prepared and their stability determined (that is, invariance of their general relative shapes under slight changes of conditions such as development time, random variation from batch to batch, etc.), a good idea may be obtained of the precision and accuracy that may be expected by using one curve for calibrating two lines which differ appreciably in wave length.

It should be reiterated that, in usual spectrographic practice only lines that have the same or very nearly the same calibration curves are compared.

TABLE II.

VARIATION OF GAMMA WITH WAVE LENGTH.

Plate—Eastman Spectrum Analysis No. 1.

Curve	*Wave length in A*	*Gamma*
A	4100	3.25
B	3840	2.70
C	3600	2.20
D	3510	2.00
E	3450	1.85
F	3350	1.60
G	3270	1.40
H	3010	1.15
I	2880	1.25
J	2740	1.35
K	2520	1.45
L	2390	1.30
M	2310	1.10

The Editor regrets that this paper is too long to permit its publication complete in one issue of the JOURNAL. *The remaining two Chapters will be published in August.*

DETERMINATION OF TOTAL SOLIDS IN BOILER WATER FROM ALKALINITY AND CHLORINITY.

By Raymond S. Kaufman.*

For the special case of feed water treatment for Naval boilers, where 100 per cent evaporated water, and a compound of fixed composition is used (Navy Standard, 1933), the total solids in the boiler water can be found by the equation (1)

$S = 2.01B + KC$ where

S = total solids in parts per million.

B = phenolphthalein alkalinity in parts per million.

K = ratio of total solids in cooling water for condenser to chlorinity in cooling water.

C = chlorinity in parts per million in boiler water.

This equation has been checked many times at this Laboratory and has been found accurate to $\pm$ 5 per cent of the total solids. Other things being equal it should be accurate anywhere else. The composition of Navy Standard Compound is: 44 per cent sodium carbonate or soda ash, 47 per cent disodium phosphate and 9 per cent starch. The fact that it is a definite composition makes it possible to arrive at equation (1). Other equations similar to (1) except for the coefficient of B can be arrived at, depending on whether different percentages are used in the boiler compound constituents, whether sodium hydroxide is used instead of sodium carbonate, whether monosodium or trisodium phosphates are used in place of disodium phosphate and whether some other colloid is used instead of starch. A general development will be traced using the percentages in Navy Standard Compound (1933) for the pertinent ratios; a general equation will be drawn up, with explanations of symbols; then the general equation will be applied

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to 1933 Navy Standard Compound, to 1941 Navy Standard Compound and method shown how it can be applied to other compounds similar to Navy Standard Compound as noted below:

Name of Compound	*Highly Alkaline Constituent*	*Phosphate Constituent*	*Colloid Constituent*
Navy Standard, 1933	44% Na_2CO_3	47% Na_2HPO_4	9% starch
Navy Standard, 1941	39% Na_2CO_3	48% Na_2HPO_4	13% starch
Compound A	X% Na_2CO_3	Y% Na_2HPO_4	Z% starch
Compound B	X% Na_2CO_3	Y% Na_3PO_4	Z% starch
Compound C	X% Na_2CO_3	Y% NaH_2PO_4	Z% starch
Compound D	X% NaOH	Y% NaH_2PO_4	Z% starch
Compound E	X% NaOH	Y% Na_2HPO_4	Z% starch
Compound F	X% NaOH	Y% Na_3PO_4	Z% starch

The following table indicates the compounds discussed and their chemical formulae:

Symbol	*Name*
Na_2CO_3	Sodium Carbonate
NaOH	Sodium Hydroxide
Na_2HPO_4	Disodium Phosphate
Na_3PO_4	Trisodium Phosphate
HNO_3	Nitric Acid
H_2O	Water
CO_2	Carbon Dioxide

The total solids in boiler water is the sum of the solids introduced by the feedwater treatment and the solids that may leak into the feed system. The solids concentration from the feed water treatment, which is a function of the alkalinity, can be determined theoretically while the solids concentration from leakage can be determined from the chlorinity. The development is rational and can be applied to any compound similar to Navy Standard Compound.

The chemical reactions of the ingredients in Navy Standard Compound (1933) in the boiler water are as follows: (The numbers on top of the chemical formulae apply to proportional weights). The decomposition of Na_2CO_3 which occurs over

$$\underset{106}{Na_2CO_3} + H_2O + \text{heat} \rightarrow \underset{80}{2NaOH} + CO_2.$$

380 degrees F.: It is seen from the equation that 106 grams of Na_2CO_3 will decompose in the boiler water forming 80 gms. of NaOH. The conversion factor by which the weight of Na_2CO_3 is multiplied to get the weights of NaOH is, $\frac{80}{106} = 0.755$, $\therefore$ 0.755 (wt. of Na_2CO_3) = (wt. of NaOH).

After the Na_2CO_3 is decomposed the pH of the boiler water will be over 11 which will favor the conversion of Na_2HPO_4 to Na_3PO_4 according to the following equation:

$$\underset{142}{Na_2HPO_4} + \underset{40}{NaOH} - \underset{164}{Na_3PO_4} + H_2O$$

Thus 142 grams of Na_2HPO_4 is converted into 164 grams of Na_3PO_4.

The conversion factor is $\frac{164}{142} = 1.155$ $\therefore$ 1.155 (wt. of Na_2HPO_4) = wt. of Na_3PO_4.

Since, from the preceding equation, it required 40 grams of NaOH to convert 142 grams of Na_2HPO_4 to Na_3HPO_4 the factor of conversion would be $\frac{40}{142} = 0.282$ $\therefore$ 0.282 (wt. of Na_2HPO_4) = (wt. of NaOH required).

The decomposition of the Na_2CO_3 in 1 gram of boiler compound yields 0.755 (.44) = 0.332 grams of NaOH.

The conversion of the Na_2HPO_4 in 1 gm. of boiler compound required 0.47 (0.282) = 0.132 grams, this would leave 0.2 grams of NaOH as excess.

The neutralization of NaOH proceeds thus:

$$\underset{40}{NaOH} + \underset{1 \text{ liter of IN}}{HNO_3} - NaNO_3 + H_2O$$

$\therefore$ If 40 grams of NaOH in 1 liter of solution has a strength of IN, 0.01N or 1 per cent N solution has 0.4 grams of NaOH dissolved in 1 liter of solution.

Then the 0.2 grams of excess NaOH per liter after the conversion of Na_2HPO_4 gives the boiler water an alkalinity of 0.5

per cent N, which is the same if titrated to the phenolphthalein end points or the methyl orange end point.

The Na_3PO_4 in the boiler water is titrated to the phenolphthalein end point as follows:

$\underset{Na_3PO_4}{164} + \underset{HNO_3}{1 \text{ liter of 1 normal}} \rightarrow Na_2HPO_4 + NaNO_3$. According to this equation 1 liter of .01N or 1 per cent N acid will convert 1.64 gms. of Na_3PO_4 to Na_2HPO_4. The amount of Na_3PO_4 formed from the Na_2HPO_4 in the compound was $1.155(.47) = 0.543$ gms. This amount of Na_2HPO_4 dissolved in a liter of water would then have an alkalinity of $\frac{.543}{1.64}$ (1 per cent) $= 0.331$ per cent. The total alkaline material formed from 1 gm. of boiler compound is then $0.2 + 0.543$ gms. One gram of compound also contains 0.09 gms. of starch. The total solids then resulting from the decomposition of 1 gm. of compound is then $0.743 + 0.09 = 0.833$ gms. The total alkalinity resulting was 0.500 per cent + 0.331 per cent = 0.831 per cent N.

Summarizing the above reactions:

(1) 0.755 (wt. of Na_2CO_3) = (wt. of NaOH) resulting from decomposition of Na_2CO_3.

(2) 0.282 (wt. of Na_2HPO_4) = (wt. of NaOH) used converting Na_2HPO_4 to Na_3PO_4 subtracting (2) from (1) gives excess NaOH after Na_2HPO_4 is converted.

(3) 0.755 (wt. of Na_2CO_3) — 0.282 (wt. of Na_2HPO_4) = wt. of excess NaOH. Since 0.4 gm. of NaOH gives an alkalinity of 1 per cent N, then the alkalinity from (3) is

(4) $\frac{0.755\ (Na_2CO_3) - 0.282\ (Na_2HPO_4)}{0.4}$ (1 per cent) = per cent N alkalinity from (3).

(5) (1.155) (Na_2HPO_4 in compound) = (wt. of Na_3PO_4 resulting). Since 1.64 gms. of Na_3PO_4 gives an alkalinity of 1 per cent N, the alkalinity resulting from the Na_3PO_4 in the compound is:

(6) $\frac{1.155\ (Na_2HPO_4)}{1.64}$ = per cent N alkalinity from the Na_3PO_4.

Combining (1) to (6) to get a general expression for the factor to multiply the alkalinity by to get total solids introduced by the compound.

(7) [wt. of total solids from compound to give solution of 1 per cent N] =

$$\frac{\text{wt. of excess NaOH} + \text{wt. of } Na_3PO_4 + \text{wt. of starch}}{\frac{\text{wt. of excess NaOH}}{0.4} + \frac{\text{wt. of } Na_3PO_4}{1.64}}$$

By multiplying the above expression by per cent N alkalinity, the total solids from the compound is obtained. Substituting symbols and adding symbol for alkalinity (α), also using formulas to indicate percentage of ingredient in compound.

(8) gms. total solids = α

$$\left[\frac{0.755(Na_2CO_3) - 0.282(Na_2HPO_4) + 1.155(Na_2HPO_4) + \text{starch}}{\frac{0.755\,(Na_2CO_3) - 0.282\,(Na_2HPO_4)}{0.4} + \frac{1.155\,(Na_2HPO_4)}{1.64}}\right]$$

Converting per cent N alkalinity to ppm. alkalinity and calling it B, [500 α = B] and changing grams to ppm. [1000 (gms. total solids) = ppm. total solids].

(9) ppm total solids = 3.28B

$$\left[\frac{0.755(Na_2CO_3) - 0.282(Na_2HPO_4) + 1.155(Na_2HPO_4) + \text{starch}}{4.1\,[0.755(Na_2CO_3) - 0.282(Na_2HPO_4)] + 1.155(Na_2HPO_4)}\right]$$

In order to see the above equation more easily and to use it for other cases it can be abbreviated by substituting symbols in equation (9).

Table of Symbols:

S = ppm. dissolved solids.

X = 0.755 (Na_2CO_3) or 1 (NaOH).

a = 0.282 (Na_2HPO_4) or 0 (Na_3PO_4).

y = 1.155 (Na_2HPO_4) or 1 (Na_3PO_4).

z = fraction starch or other colloid.

B = ppm. alkalinity to phenolphthalein end point.

Note: (a) Formulas designate (percentage) in boiler compound.

(b) x — a must be zero or more.

(c) The alternative values for x, a, and y indicate that their fractional part in the boiler compound is to be used in the equation e.g. in Navy Standard compound (1933), x = 0.755 (Na_2CO_3) = 0.755 (0.44) since this boiler compound contains 44 per cent of Na_2CO_3.

$$(10)\quad S = 3.28 \left[\frac{(x - a) + y + z}{4.1\ (x - a) + y} \right] B$$

Finding factor for Navy standard comp. (1933)

$$x = 0.755\ (0.44) = 0.332.$$

$$a = 0.282\ (0.47) = 0.132.$$

$$y = 1.155\ (0.47) = 0.543.$$

$$z = 0.09.$$

$$(11)\quad S = 3.28 \left[\frac{(0.332 - 0.132) + 0.543 + 0.09}{0.816 + 0.543} \right] B$$

$$(12)\quad S = \frac{3.28\ (0.832)}{1.359} B = 2.01\ B = \text{ppm. solids from 1933 Navy Standard Comp.}$$

The solids in boiler water introduced by leakage is determined by evaporating a sample of the raw water for total solids, analyzing the raw water for chlorine determining the ratio of total solids to chlorine and multiplying the chlorine in the boiler water by that ratio. The total solids in ppm. in boiler water with 100 per cent evaporated water for feed and treating with Navy standard compound (1933) is finally,

$$(13)\quad \text{Total } S = 2.01\ B + (\text{ratio})\ (\text{chlorinity})$$

In order to indicate how equation (10) can be applied generally the factor for 1941 Navy standard compound is determined. This contains 39 per cent Na_2CO_3, 48 per cent Na_2HPO_4 and 13 per cent starch.

$$X = 0.755\ (0.39) = 0.294.$$

$$a = 0.282\ (0.48) = 0.135.$$

$$y = 1.155\ (0.48) = 0.554.$$

$$z = 0.13.$$

$$(14)\quad S = 3.28\left[\frac{(0.294 - 0.135) + 0.554 + 0.13}{4.1\ (0.294 - 0.135) + 0.554}\right] B = 2.29B$$

Another example of how equation (10) can be applied. A compound of hypothetical composition, 40 per cent NaOH, 50 per cent Na_3PO_4, and 10 per cent starch is used.

$$X = 1(.40).$$

$$a = 0$$

$$y = 1(.50).$$

$$z = 0.1.$$

$$(15)\quad S = 3.28\left[\frac{(0.4 - 0) + 0.5 + 0.1}{4.1\ (0.4 - 0) + 0.5}\right] B = 1.53B$$

Equations (14) and (15) were not checked at this Laboratory, but were included solely to indicate how equation (10) could be used. If the compounds have constituents of constant composition and fall into the category of compounds similar to Navy standard compound (1933), equation (10) should be generally applicable.

NOTES.

INDEX TO NOTES.

THE BRITISH MERCHANT SHIPBUILDING PROGRAM IN NORTH AMERICA, 1940-42.
—North-East Coast Institution of Engineers and Shipbuilders, Nov. 1942.

EXHAUST PIPE PHENOMENA.
—British Motor Ship, January, 1943.

STRUCTURAL FAILURE OF THE TANKER S.S. "SCHENECTADY".
—American Bureau of Shipping, March 16, 1943.

BLACKOUT LIGHTING.
—General Electric Review, December, 1942.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

Cellophane Bubbles.
—Pacific Marine Review, January, 1943.

The Physical Bases of Seizure.
—Engineering (London), December 18, 1942.

Columbian in High Temperature Steel.
—Metals and Alloys, January, 1943.

Solar Radiation as a Power Source.
—Military Engineer, February, 1943.

THE BRITISH MERCHANT SHIPBUILDING PROGRAM IN NORTH AMERICA, 1940-42.

Mr. R. C. Thompson, C.B.E., Member of Council, and Mr. Harry Hunter, O.B.E., Vice-President, of the North-East Coast Institution of Engineers and Shipbuilders, presented this eleventh Andrew Laing Lecture at a General Meeting of the Institution on November 27, 1942. Messrs. Wm. Bennett, J. S. Heck and R. R. Powell, and the authors constituted the Technical Merchant Shipbuilding Mission which arranged the British purchase of 86 ships in the United States and Canada.

Section 1.

PRELIMINARY AND NEGOTIATIONS.

Early in September, 1940, the Authors were invited by the Admiralty to proceed to the United States as members of a Technical Merchant Shipbuilding Mission, Mr. Thompson being head of the Mission and Mr. Hunter the Marine Engineer member.

942. The object of the Mission was to endeavor to obtain, at the earliest possible moment, the delivery of merchant tonnage from U.S.A. shipyards at the rate per annum of about 60 vessels of the tramp type of about 943. 10,000 tons deadweight. The work of the Mission was to be considered as completed at the stage at which orders were placed, or provisionally placed, and settlements made as to technical details. Before leaving, we were also informed that it was hoped that it would be found possible to 943. arrange for the Mission to investigate possibilities of merchant shipbuilding in Canada, and this authority was actually received soon after we arrived.

942. We reached New York on 3rd October, and the first full meeting of the Mission took place in New York on 4th October. After making various contacts in New York and Washington, we met Todd Shipyards, Inc. and found they were associated with a group of Pacific Coast civil engineering 943. contractors known as Six Services Inc. headed by a Mr. Henry J. Kaiser, and jointly they owned the Seattle-Tacoma Shipyard. They produced a nicely colored drawing of a modern British tramp steamer, and offered to 942. build ships for us, providing they had reciprocating engines and water-tube boilers—Scotch boilers might be possible—and a specification generally to 943. meet the special conditions. We also met representatives of other shipbuilding concerns, several of whom undertook to look into the matter.

We then proceeded to Ottawa, and met Hon. C. D. Howe, Minister of Munitions and Supply, and his Director of Shipbuilding, Mr. D. B. Carswell—again it seemed that reciprocating engines were the only hope, and they could do Scotch boilers.

We then commenced a general examination of the possibilities in Eastern Canada, after which we returned to New York, meeting various shipbuilders and prospective shipbuilders, and on October 15th we started a tour of the American continent visiting existing shipyards and engine works, works which might build engines or boilers, and sites where shipyards could be built.

By this time, an association of Todd, Bath Ironworks, and Kaiser group and also Burrards, Canadian Vickers and Davie Shipbuilding Co. had undertaken to submit tenders. We finished up with three contracts for each yard, in each case one being for the yard, one for 30 ships, and one being a guarantee contract signed by the respective stockholders. Contracts were signed on 20th December, 1940, as between His Majesty's Government, represented by the British Purchasing Commission on the one hand, and Todd-Bath Iron Shipbuilding Corporation, Portland, Me., and secondly, Todd-California

Shipbuilding Corporation, Richmond, Cal., on the other, covering the building of the two shipyards and 30 ships at each yard in addition to guarantee contracts signed by the respective stockholders.

Shortly afterwards orders for 26 vessels were placed with the above-mentioned Canadian yards.

Section 2.

THE TODD BATH AND TODD CALIFORNIA SHIPYARDS AND CANADIAN SHIPYARDS.

The Canadian yards being in existence we were only concerned with the U.S. yards and sites, and had to satisfy ourselves that what was proposed would (*a*) do the job, and (*b*) do it without any unnecessary expenditure.

Richmond, California and Portland, Maine, were proposed by Todd as being good sites in good situations as regards available labor, &c., and accepted as such. Each were to have seven berths. Richmond Yard was to be built entirely on piles and arranged as a normal yard as regards launching. Portland, which had a rock foundation, was proposed as a series of shallow drydocks or basins. It was agreed that, although the latter would take a little longer to build, it would not cost much more, and the ships would be cheaper and quicker built owing to being built on the level and eliminating launch costs. Actually both yards cost us about the same amount, while the ships were produced more quickly at Richmond due to causes referred to later.

The layouts of the yards are fairly similar (see Figures 1 and 2). Portland had 25 ton cranes, Richmond 35 ton, largely on account of delivery conditions. Both yards found out the difficulty of trying to build ships with one crane per berth and various improvisations were adopted to get over this. On account of lack of space, Portland had to take over a large area of ground three miles from the yard, for storing steel, boilers, engines, and most of the other sub-contracted material. This storage space had a direct rail connection which the yard had not, so special road vehicles were used between the two places owing to high cost of laying rails and right of way difficulties. Richmond had direct rail access and storage on the site. The Portland Yard was only possible as a shallow drydock proposition on account of the particular nature of the ground where suitable rock foundations were found at the right level in association with a small rise and fall of tide. Even so, pumping had to be resorted to on a considerable scale, and this led to difficulties under the hard winter conditions encountered in this locality. It is, unfortunately, not possible to say which is the cheaper method of building on account of differences in conditions. The fact remains that Richmond delivered 30 ships by July, 1942, 19 months from signing the contract, while Portland look like completing their 30 by November, 1942—within contract but definitely second, in spite of the fact that many more people with shipbuilding experience were engaged at Portland.

The Portland Yard involved considerably more civil engineering than the Richmond Yard, and the latter yard had the advantage, as it transpired, of the civil engineer being also the shipbuilder. Also the Kaiser Company was just completing the big Grand Coulee Dam contract and was able to bring in a highly efficient team well experienced in the handling of bigger contracts than the traditional shipbuilder. The West Coast weather was also more favorable, with no frost or blizzards, although the months of February and March were definitely damp. The construction work at Richmond, however, was very considerable, involving the driving of about 25,000 piles up to 70 feet long which, at the maximum, were driven at the rate of 700 per day, while the ground at Portland was still largely frozen. In fact, the Kaiser group have not only built 30 British ships in record time, but

they have set up several other yards comprising 50 berths or more, all of which are doing equally well, and they can claim to have set a high standard to the world in the mass production of good ships. Anyway, in the event they more than justified the confidence placed in them.

To return again to Canada, the contracts which we placed were with existing yards. Working plans had to be supplied from Britain—riveting was feasible and preferred by the Canadian builder, so our orders were placed for mainly riveted vessels following very closely the British design. We could have obtained the welded plans from the U.S. builders, but that would have meant building new shipyards or making very substantial modifications as would be the case here. The equipment would have had to come from U.S.A., which would have meant delay. The Canadian yards, therefore, went ahead on our orders, on the basis of mainly riveting and part welding, and when the Canadian Government formed the organization, "Wartime Merchant Shipping Ltd." to step up Canadian shipbuilding, that organization followed our example and standardized our ships. The results they have achieved proved the wisdom of that decision. They made the best use of available labor and materials as we have done. The arguments in favor of welding versus riveting are far from being settled and, although the former is put forward as being the *modern* method, all the evidence shows that it involves more labor in the building of ships. Its advantages are that less capital cost is involved if a new shipyard is being laid down, and welding equipment is more readily available, and there is a saving of steel. This latter feature is of great importance when contemplating a shipbuilding programme of the magnitude of that now being undertaken in the U.S.A. but, in this country and Canada, the labor side of the problem is at least equally important, if not more so.

Section 3.

Modifications to Specifications.

(An outline hull specification is given in Appendix A and a capacity plan in Figure 28)

The parent British vessel from which the design of the 60 American-built *Ocean* type ships was evolved, was the *Empire Liberty* built by Joseph L. Thompson & Sons Ltd. There are slight differences in dimensions, as shown in the following tables:—

	Ocean type		*Empire Liberty* type	
Length b.p., feet and inches	416	0	416	0
Breadth ext., feet and inches	57	0⅜	57	2
Breadth moulded, feet and inches	56	10¾	56	10½
Draught ext., feet and inches	26	10⅞	26	11¾
Draught moulded, feet and inches	26	10	26	9⅝

Both types—Camber 2nd deck—nil ; upper deck 14 inches.
Sheer 2nd deck—nil ; upper deck 8 ft. 9 in. fwd., 4 ft. 6 in.aft.

To suit U.S.A. practice, to ensure a good supply of labor, to facilitate production, and to get the best value for money, it was decided that the ships must be mainly welded. In fact, practically the only rivets left in were the connecting rivets of frames and shell. This was in accordance with established practice in a number of U.S.A. yards, though one or two preferred all-welding, while a number of others welded everything except shell seams. To produce an all-welded ship involves making elaborate formers for laying outside shell correct to shape in order to weld frames thereto down-hand. It was not considered that the number of ships involved in these contracts justified such a procedure.

Figure 3 shows the midship section adopted at this stage.

Other modifications to the specification agreed upon were as follows:—

The substitution of cast steel or fabricated mild steel for cast iron—the latter is very little used in America and cast steel is very reasonable in price there. In fact, the cast-steel stern frames were the only thing in the ship found to be cheaper in U.S.A. than here. Hawse pipes were made of cast steel, also fairleads, while bollards were fabricated mild steel or cast steel.

Electrical fittings.—U.S.A. electrical practice was found to vary considerably from British, but it is too wide a subject to deal with in this paper. It is felt that firms handling this work in this country would find much of interest if they examined any modern American vessel.

Wood-work.—In the U.S.A. wood-work is almost invariably subcontracted by the shipbuilder so that furniture is designed for mass production and simply fitted on board. Wood decks are practically unknown, the usual practice being to insulate deck-heads in accommodation with asbestos wool, about 1½ inch thick, interwoven with wire netting. This is fitted close to the steel and lined with plywood under. It may be mentioned here that pre-war American Rules did not allow wood in the accommodation at all, and all furniture was steel, while bulkheads and linings were made of thin steel bonded to asbestos. The general finish produced was such that it needed a knife to prove wood was not used. This practice was, however, much more expensive, so plywood was used in the British ships, and the American Rules have now been waived in their Emergency Programme to facilitate production. Teak was practically unknown and American white oak used in its place.

The *Rudder* was made of fabricated mild steel and cast steel but according to a rather interesting American design which apparently gives very good results.

Steering Gear.—As very few large American steam gears had been produced in recent years it was decided to have gears manufactured in U.S.A. to British designs, and the same remarks apply to windlasses. Designs for the former were supplied by Messrs. John Lynn & Co. Ltd., and the latter by Messrs. Emerson, Walker, Ltd. The Taylor Pallister design was used for rudder carrier.

In Canada, it was found advisable to make modifications from both the American and British specifications as referred to later. The Canadian Yards were, at that time, all in existence, and mostly they not only had considerable repair businesses but they were already building corvettes and mine sweepers of mainly riveted construction. The Canadian Yards wanted all plans supplied, so it was decided that they would work to British plans, but that individual firms could introduce more welding with our and classification approval. Revised plans covering introduction of additional welding were prepared by The Burrard Drydock Co. Ltd. for use in all Canadian Yards. In Canada, steel was in short supply, so that most of the yard facilities were made of wood, some of the work being very ingenious, such as 10-ton wood cranes travelling between berths and wood gantry cranes. Alterations in Canada included, in some cases, the following :—

Wood topmasts, instead of steel ; wood decks (B.C. fir) over accommodation, wood derricks, instead of steel, cotton canvas instead of flax (applies to U.S.A. also). Welding was agreed upon for the following:—keel and shell—butts ; tank top—butts and seams ; decks—butts and seams ; bulkheads—butts and seams, also all connections to tank top. Bilge keel—welded to shell ; second deck stringer welded to shell ; tank margin welded to shell and tank top ; bilge brackets welded to margin with continuous gusset plates welded to margin ; floors welded to margin plate ; centre keel

welded butts. These items were specifically approved in view of the fact that careless intermingling of welding and riveting can cause trouble both during construction and later.

A big problem was involved by the lack of detail in British plans which required very considerable interpretation and amplification, but the members of the Mission were able to cover most points in this respect, and also arrangements were made for the representatives of the shipbuilders to inspect British ships of the type concerned in port. This aspect is gone into more fully later on in the Machinery Section.

Other problems included difference in pipe and flange standards, and such items as U.S. or Imperial gallons, long and short tons, timber sizes, hemp- and wire-rope sizes, &c., &c.

Another consideration which was very fully gone into in conjunction with Lloyds concerned the scantlings advisable in a mainly welded ship. For instance, it was decided to keep the longitudinal, vertical, and horizontal moment of inertia of the section the same as for a riveted vessel. Also it might be mentioned that, with 30-inch frame spacing, the plating span is only 26½ inches from heel to toe of frame, whereas with welded structure the span is 29½ inches. To compensate for this, such things as keel thickness were increased 10 per cent. This has been proved necessary to avoid knife-edge effect when in drydock. For these reasons, the saving in weight due to welding is not as much as might at first be expected. Our M.O.W.T. regulations also required specific definition in both U.S.A. and Canada.

Section 4

Centralization of Design and Purchasing

Gibbs & Cox are a firm of consulting naval architects in New York, and they were employed not only to do all the work usually carried out in a shipyard drawing and design office, but also to purchase all materials required for building the ships, both hull and machinery. Only small items purchased locally were to be bought by the shipyards themselves. To give an idea of the size of this organization, it may be mentioned that, at the time of our discussions, they were employing a staff of between 900 and 1000. In our case, their function was to produce a new set of plans, based upon those provided by us, but modified as regards the substitution of welding for riveting, and to suit American practice regarding sections obtainable, size of plates, pipes, etc. For instance, shell plates, 40 feet long by 10 feet broad were obtainable while bilge keels could only be obtained by cutting the flange off a bulb angle. Then Gibbs & Cox were to purchase all the major items—main engines, boilers, shafting, propellers, auxiliaries, steering gears, windlasses joiner work, plates, sections, rivets, welding rods, stern frames, rudders, electrical installations, sidelights, boats, davits, upholstery, to name a few, and even bolts and nuts, and arrange for everything to be delivered at the shipyard at the right time. As an illustration of the detail involved in this work, it was their practice, in the case of large contracts, to make a model of the engine-room and everything in it, complete in every detail to a scale of ½ inch to the foot, in order to determine the best lead of all pipes, electric cables, etc., all of which would be completed on the model and then incorporated on all drawings. In other words, nothing whatever was left to be arranged on the ship. This practice had been proved to save endless time and argument in the shipyards where local surveyors were responsible only for seeing that all plans were exactly followed.

In the case of our contracts, a model of the machinery space was not made as the British plans gave a good basis. In the case of the Maritime Commission *Liberty* class such a model was made—the change to oil-fired

water-tube boilers necessitating very substantial re-arrangement. A model covering both classes of ships was made of the fore-end in connection with anchor cable and paravane leads.

The wisdom of utilizing the services of an organization of this sort was confirmed by the fact that the U.S. Maritime Commission, when it started its Emergency Programme involving hundreds of ships, followed our example. Incidentally, they also accepted and followed our hull design as well as our main engine design, and they also standardized on practically the same auxiliaries and equipment as those used by us. In fact, the main differences between our ships, the *Ocean* class, and the Maritime Emergency ships E.C.2 type, also known as the *Liberty* fleet, lie in their re-arrangement of the accommodation to house the whole crew amidships, and the adoption of water-tube boilers and oil burning. It should be stated, however, that with the further extension of the Maritime Commission programme, involving thousands instead of hundreds of ships, they set up their own organization in Washington.

Section 5

Comparison between U.S.A. mainly welded vessels and British mainly riveted vessels

It has already been published that the man-hours required to build these vessels in the U.S.A. are about double the number required in this country, and great credit has accordingly been paid to our shipyard workers. The shipyard workers are also known to be working really well on the other side of the Atlantic, so that it is natural that one would wonder whether the high number of man-hours required in the U.S.A. is due to the fact that they are building welded ships, and whether there are other contributory factors or other explanations. An average figure for this particular type of ship here is about 336,000 man-hours direct labor. This includes installing the machinery, also the electrical installation. It also covers all blacksmith work, some of which is sub-contracted in U.S.A., all plumber work except the cabin heating installation, and it includes all joiner work whereas, in many cases in U.S.A. the furniture is bought outside. The figure does not include upholstery work, or bituminous work, or the manufacture of such things as ventilator cowls. The only corresponding figure so far published for Canada, and which referred to one of their first ships was about 600,000 man-hours. The early U.S.A. figures were generally rather more, but after 20 ships the figure for the Todd-California Yard was 510,000 man-hours. More recently, however, we have learned that the famous vessel built by Henry J. Kaiser, in the remarkable time of 14 days, involved only 375,000 man-hours, and further improvement is expected. These figures are for direct labor only so far as can be ascertained, and it appears that indirect labor also involves a very substantial number of man-hours in U.S.A. amounting roughly to a further 20 per cent compared to an average figure of 5-10 per cent here. It appears, therefore, that whereas the welded ship requires less steel, it requires more man-power and that, therefore, in all the circumstances prevailing in the U.K. today, and particularly the shortage of man-power, our methods generally provide a rational compromise between the two factors.

In considering this matter, however, the following points need to be borne in mind :—

(1) The new American Yards were designed specifically for the mass production of one particular type and size of ship, whereas existing yards, both here and in the U.S.A. are able to build efficiently a large variety of different sizes and types of vessel.

(2) In America, they are building ships with "butchers, bakers and candlestick makers." Probably in most of the new yards less than 10 per cent and, in some cases, only 1 or 2 per cent of the men had been employed in shipbuilding before. In the case of Todd-California, only a small proportion of the management had been in a shipyard before, and the same thing applied to a greater extent in several other yards. The men in the yards were, however, remarkably keen and intelligent, and soon learned the job as is proved by the amazing results achieved. Many of the men were, of course, skilled craftsmen, but not in shipbuilding, while foremen and management were used to handling big engineering jobs of various sorts, such as the building of the Boulder and Grand Coulee Dams, the latter being the largest in the world.

(3) The remarkable speed of building—the target of at least one ship per berth per month—is probably a most important and fundamental factor.

(4) The equipment for a new shipyard for building welded ships costs less and is more easily obtained than the equipment for building riveted ships. A much larger site area is required per berth for welding, although this may well be offset by the increased production per berth, leaving us with approximately the same output from a given area.

(5) It is much easier to train good welders than good riveters. Females can and do weld, but they cannot rivet. The average man would prefer to weld rather than rivet.

(6) The science of building welded ships is still in its infancy, and improved methods are continually being involved. In this connection it is believed that we in this country are practicing more up-to-date hand-welding methods than in America where much of the thought has been given to machine welding which has at present only very limited application in shipbuilding. Early figures for the Todd-California show that less than 10 per cent of the total welding was done by machine. Feet/man/day were given as 53 for machine welding and 17 for manual welding. The machine can only be used for straight down-hand work however. A.c. welding is only used in U.S.A. for machine welding. Hand welding is done with d.c. generators mostly of the single-operator type. A typical yard had the following equipment for 14 berths :—

142—400 amp. single operator d.c. sets ; 673—300 amp. single-operator sets ; 327—200 amp. single-operator sets, together with 21 constant potential d.c. 1500 amp. multi-operator generators. The 400 amp. sets were used for down-hand work, using rods up to 5/16 inch. We use currents of 450-500 amps, with 5/16-inch rods to apply them at maximum speed. Furthermore, a transformer type, a.c. welding unit will do the same work as d.c. single-operator sets with about 10 per cent less current consumption. D.c. constant potential generators are still less efficient.

(7) The question of repairing welded ships requires special consideration. Generally speaking, repairers have been welding for longer than builders. but unfortunately this has resulted in repairers knowing far more about antiquated methods of welding than they do about modern methods. The 200 amp. welding set and bare-iron wire are still, in some cases, the ship-repairers' friends while both are unknown, fortunately, in shipyards. The fundamental principle followed while building welded ships is so to arrange the sequence of work that *contraction while welding can take place.* This is sometimes impossible when carrying out a repair. Repairs, therefore, in a highly stressed part of the ship's structure are going to be very difficult in a welded ship by welding. Pending further developments, it may prove better to do repairs in such areas by drilling and riveting. An example would be the renewal of a stringer or sheer-strake plate amidships. If a rectangular plate in such an area were cut out and a new plate welded in,

trouble would probably follow owing to the combination of welding stresses and service stresses. This matter deserves the closest study by classification societies, and the suggestion is put forward that such a plate should be cut out and replaced in accordance with Sketch 1 in order to make the service stresses cross and not combine with the inevitable residual welding stresses. Alternatively, the butts of such a plate might be doubled by diagonal patch doublers welded on the underside as in Sketch 2.

1.

2.

If some such measures are not adopted, the combination of residual welding stresses and service stress conditions will almost certainly cause fractures at or near the welds, and the welding will get a bad name which it may not deserve as the cause will be "faulty application of welding." Examples of this have already occurred, and it is considered that it should be the responsibility of the classification societies to prevent such mistakes, although undoubtedly shiprepairers should study the subject technically.

Section 6.

Methods of Building in the U.S.A. and Canada.

Labor. In both the U.S.A. and Canada labor was available in quantity—there were 12,000,000 unemployed in the U.S.A. at the beginning of the war—having a high average of intelligence and mechanical aptitude with a large proportion of skilled craftsmen among them, although practically none had previous shipbuilding experience. The above should be borne in mind when reading newspaper reports about the building of ships by butchers, bakers and candlestick makers. Also, the yards were laid out for, and engaged on, repetition of the identical ship in quantity so that men were largely on the same job time after time—an essential to the efficient and quick utilization of raw labor. With this went an elaborate system of production planning including very complete breakdown of the plans into component details.

Under such conditions a man without previous experience, but with aptitude, very quickly becomes an efficient worker ; in the Richmond Yard early this year (1942) when that yard was one of the leaders in rapid building and in economy of man-hours per hull, the total number of employees was about 10,000 of whom 87 per cent had no experience in shipyards. About 7 per cent were classed as trainees and 20 to 25 per cent as helpers. Of about 1100 welders employed 650 had been trained in the yard and also large numbers of yard trained men had transferred to associated yards. In this connection it may be noted that the first keel was laid in April, 1941, and the first launch took place in August, 1941, and 30 ships were launched by June, 1942.

Other U.S. yards had even higher percentages of men with no previous experience, and in the case of one large 11-berth yard which has set up some recent remarkable building records the percentage of men with no previous shipyard experience is believed to be over 95. This particular yard launched its first ship in September, 1941, and 54 by August, 1942, and the Authors recall that the production planning set up was one of the most complete in the U.S. Most of the men seemed to be able to get started either as journeymen or helpers without much difficulty, often with very little previous experience in their trade. The procedure was for men to apply at the yard where particulars of their past history were taken and if the personnel management department of the yard felt that they were suitable for a particular trade, things were arranged so that the men could get their union card from the local "business agent."

TABLE 1

Trade	Our Definition	Journeymen	Helpers	Trainees	Total
Blacksmiths ..	Blacksmiths	21	4	—	25
Boilermakers ..	Riveters—Platers—Caulkers	30	811	—	841
Chippers	Cutters	236	15	49	300
Drillers	Drillers	122	—	—	122
Flangers	Platers	452	35	46	533
Riggers	Riggers	76	—	—	76
Plate cangers ..	Platers and helpers ..	264	—	5	269
Pressmen	M/c operators	18	—	—	18
Riveters and holders on	Riveters and holders on	52	—	—	52
Rollermen	M/c operators	6	—	—	6
Slabmen	Frame turners	13	55	—	68
Electricians	Electricians	222	54	16	292
Slingers	Slingers and helpers ..	178	—	—	178
Engineers	Fitters	182	—	—	182
Machinists	Fitters and machinists	121	158	—	279
Painters	Painters	165	—	—	165
Pipe fitters	Plumbers and fitters ..	266	279	—	545
Steam fitters ..	Plumbers and fitters ..	38	20	—	58
Sheet-metal workers	Sheet-metal workers ..	56	34	—	90
Ship fitters	Platers and helpers ..	309	314	309	932
Loftsmen	Loftsmen	6	—	2	8
Steel checkers ..	Iron yard labourers ..	43	—	—	43
Material checkers ..	Storekeepers and stock-takers	5	—	—	5
Shipwrights ..	Shipwrights	212	127	19	358
Stage riggers ..	Shipwrights & labourers	202	—	—	202
Ship joiners ..	Ship joiners	134	—	—	134
Burners	Burners	348	—	56	404
Welders	Welders	1,547	239	85	1,871
Labourers	Labourers	716	—	—	716
		6,040	2,145	587	8,772

Regarding rates of pay, the work was mostly done on a time basis but hourly rates were good and every man is expected to work at what we would call piecework speed. Rates paid on the Pacific Coast yard were as follows :—Journeymen (all classes), $1.12 or say 5/6 per hour ; helpers (all classes), 87 cents, or say 4/3 per hour ; trainees were normally recruited from helpers and went through three stages each lasting about two months,

the corresponding rates being 97 cents., $1.02 and $1.07. Apprentices and apprentice schemes do not exist. Day-shift men worked 48 hours per week and were paid for 52 hours as over 40 per week were paid at time-and-a-half. Second shift worked 45 hours and were paid 52 and third shift worked 42 hours and were paid 52. Journeymen's rate on second shift was $1.232 per hour and third shift $1.288 per hour. Journeymen could be promoted to act as leadermen (similar to our chargemen), when they got 10 per cent increase. These rates of wages are of course associated with a higher cost of living than that which applies in this country. All journeymen, no matter what their trade, got the same standard rate. There was very little interchange between trades, but the sort of thing that happened was that an ordinary laborer would be promoted to a helper in a skilled trade and could soon work up from that to a tradesman if he showed ability. A subdivision of employees by trades is given in Table 1, and the British definition of the trade has been added.

From the Table it will be seen that in the U.S. yards they not only have all our "trades" but a few more as well. Their definitions are, however, rather more clear-cut, with the result that demarcation problems are less noticeable.

It should be mentioned that there are only two Unions in the U.S.A.—the C.I.O. and the A.F. of L. Any particular firm deals with and recognizes either one or the other. Both unions have departments covering particular trades but any particular firm only has one union to meet—not a different union for each trade as we have—and the same principle appertains though to a lesser degree in Canada. It has many obvious advantages as compared with our system, not the least being the minimizing of demarcation problems.

Production. Beginning with the loft it was found that Mould Lofts generally were very much larger than in this country. Special care was taken with the design of the mould-loft floor to avoid expansion and contraction due to temperature changes and this was usually done by laying the usual wood floor strongly constructed and on top of this wood floor a hardwood parquet floor. This hardwood floor was polished and the lines were marked out in pencil instead of the usual method of a black floor and chalk lines. The object of this was to ensure absolute accuracy because from this floor templates were made covering every individual part of the ship. Templates were made of specially seasoned timber and in some cases of special paper, while in other cases, of sheet metal.

The next process was to cut the various plates and sections correct to shape and this was nearly always done by oxy-acetylene flame cutting. Many different and elaborate types of flame-cutting apparatus were in use, one of the most notable refinements being the mounting of the burners on floating heads so that the distance of the burner from the plate was automatically adjusted and consequently plates did not have to be perfectly flat before burning. The bevelling required to suit welding was usually done in the same manner and at the same time as the cutting process. Flanging machines were usually installed ; also, the usual shell rolls. Other special machines were provided for the shaping of plates. In this connection, although we build similar ships without furnacing any plates at all, in America they find it easier to make special moulds and furnace or press any plate having an undue amount of shape, thus avoiding the rather specially skilled occupation of rolling plates having a double set, and also ensuring absolute accuracy of the shape of the plates and simplifying the fitting of them into welded structure.

Frames were turned in exactly the same manner as here, the furnaces usually being oil fired.

It will be seen, therefore, that very little normal shipyard machinery was used and the whole of what might be called the skilled operation of shipbuilding was really done in the loft.

The next process was the erecting of the various plates and sections into sub-assemblies, which might weight anything up to about 50 tons and in some of the yards now very much heavier weights can be handled. These sub-assemblies were designed to avoid turning over as much as possible during the welding operation which is carried out on skids on the ground. The intention was that enough space should be allowed so that all the sub-assemblies required in the ship could be ready before the berth was vacant and in this connection it has been found that in the original British yards in the U.S.A. the space allowed for storing the sub-assemblies was not nearly sufficient in relation to the very high speeds of production which are now being obtained. Such speeds, however, were not contemplated at that time and the original design of the Richmond and Portland Yards contemplated an output of 39 ships per annum whereas actually it appears that the capacity of the Richmond Yard is nearly three times, and the Portland Yard nearly twice, the number of vessels originally contemplated. When the berth became vacant the sub-assemblies were then transported and erected in the berth in accordance with a sequence plan and chart reproduced herewith and shown in Figures 6 and 7. These plans show the method of sub-division and the order of assembly agreed upon between the Mission in the first place with Gibbs & Cox.

Alternatives naturally developed as experience was gained and the following comments on the alternatives may be of interest, although most of these developments took place too late for adoption in the British contracts :—

Bottom shell—originally this was arranged to be laid out plate by plate in the berth and machine welded on top, hand overhead welding being adopted underneath. Later, sections were laid out on the skids about 60 feet long, and these sections were then turned over to enable machine welding to be done on both sides. The sections were then assembled in the berth and the joints machine welded on top and hand welded overhead underneath. This enabled more work to be done before a berth was vacant. Floors in sections already welded to the tank top on the skids were then put in place. This remained general practice.

Pre-fabricated bulkheads and side shell bolted to frames up to second deck were next erected. Later, sections of side shell were riveted to the frames on the ground before erection and to enable this to be done the original staggered shell butts were re-arranged so that welded butts in line were adopted. We were rather nervous about having butts in line, but experience does not seem to have justified our feelings.

Hatch-end beams and girders were next erected followed by sections of second deck already welded to beam. Later, both hatch beams and hatch side girders were welded to sections of deck plating and beams on the ground and lifted into place as units with butts in line with hatch and casing corners. Side shell was next pulled in and faired to the decks and welded thereto and the frame feet brackets welded to tank top.

'Tween deck bulkheads and 'tween deck frames already riveted to the sheer strake in sections about 60 feet long were next erected followed by upper-deck hatch-end beams and girders and sections of deck. The same development took place as regards the attachment of upper-deck hatch-end beams and girders to sections of deck as in the case of the second deck. Stringer butts were, however, generally kept well clear of the grouped shell and deck butts. Top side shell was then pulled in and welded to upper deck, 'tween-deck frame feet welded, and the ship was then ready for the erection of deck-houses which were generally pre-fabricated entirely as units on the ground.

The ends of the ship, i.e. from fore-peak bulkhead forward and from after peak bulkhead aft, were laid out and built up as pre-assemblies on the ground, the cruiser stern also being made as a separate unit on the ground and the whole of these units were transported complete to the berths. Between these end assemblies and the main midship body, however, an appreciable amount of material was assembled in the berth in the form of individual plates and frames as far as the shell was concerned.

The method described above involved the lifting of weights up to about 50 tons and these weights were generally handled by two cranes of 25/35 tons capacity.

In accordance with the U.S. custom main engines, boilers and shafting were installed on the berth, thus enabling the decks to be closed and work amidships to proceed before launching.

Section 7—Machinery.

General.

Before the Mission left England it was recognized that the usual type of British tramp-ship machinery, namely, reciprocating steam engines with coal-fired Scotch boilers, was not available to any extent in North America, and while this was the preferred type, the Mission was left a free hand in the matter of machinery type. Such machinery was looked on in the U.S. as archaic, particularly the use of coal as fuel for ocean-going ships; however, at the end of 1940 coal was certainly a fuel still readily available to Britain and it seemed advisable from the manning point of view to adhere to a familiar type of machinery with the avoidance of anything of the nature of a "technical adventure." It is of interest to note that the U.S. Maritime Commission adopted the identical main-engine design and much other equipment for the *Liberty* ship programme; in that case the primary consideration was that of getting into rapid production on a large scale.

A preliminary survey in the U.S. confirmed that such machinery was not available as a regular product, that a large production capacity was available with suitable plant, but that in the case of many items no suitable substitute was available, and we would have to supply the designs to firms deemed competent to execute same.

In the case of other items U.S. equipment was available of different design to the British, but otherwise suitable, and in such cases the U.S. equipment was adopted.

In Canada the situation was rather different as the Admiralty already had corvettes under construction with similar machinery to that in the proposed freighters, and firms were already in production on much of the required equipment to British designs. Apart from this, Canadian shipbuilders and associates were more familiar with British practice and requirements.

The above circumstances account for the U.S. built *Ocean* Class having a mixture of U.S. and British design equipment, all made in the U.S., while the Canadian-built *Fort* Class have mostly British-design equipment of British or Canadian manufacture.

A further factor governing the arrangements for manufacture of the larger mechanical equipment was the necessity for getting into production quickly as it was early evident that the shipbuilders might well have ships ready for equipment unexpectedly early.

The detail investigation into all the above matters was carried out in the U.S. by Messrs. Gibbs & Cox acting, as previously described, as design and purchasing agents for Messrs. Todd-Cal. and Todd-Bath Iron, and in Canada initially by the shipyards co-ordinated by the Shipbuilding De-

partment of D.M. and S., and latterly, as the programme expanded by Wartime Merchant Shipping Ltd., an organization previously referred to and set up by the Canadian Government for co-ordinating shipbuilding in Canada. Contracts for all the main items were entered into during January and February, 1941.

Section 8—Machinery.

Specification and Technical Notes.

In Appendix B is given a specification of machinery in both U.S. and Canadian ships.

The main engine contract in the U.S. for both yards was with the General Machinery Corporation of Hamilton, Ohio—a concern which includes Messrs. Hooven Owen & Rentschler, the well known former marine-engine builders. This company had built large numbers of marine engines in 1918 to 1920, but since that date had built virtually no marine engines. The contract with this concern for 60 main engines was entered into in January, 1941, and the first engine was delivered on July 7th, 1941, and the 60th on January 1st, 1942, and during the two months of December, 1941, and January, 1942, 27 engines were delivered.

The design of main engine was British (North Eastern Marine) and engines to the same drawings were fitted in the Canadian ships and also in the Maritime Commission *Liberty* Class.

Figures 19 and 20 are photographs of maine engine giving front and back views. This arrangement permitted the interchange of engines in the various programmes, and, of the above mentioned 60 engines, 30 were fitted in Maritime Commission ships and subsequently replaced by engines built against Maritime Commission orders. This interchange, and others of a similar nature, was effected under an agreement with the Maritime Commission, which finally resulted in both U.S.A. and British programmes drawing as required from common production lines.

In Canada the main engines for original British contracts were built by the Dominion Engineering Works Ltd., Montreal, and Canadian-Vickers Ltd., Montreal. These firms had built during the preceding twelve months a number of corvette engines, and were able to get into production rapidly and meet all shipbuilders' requirements. Eventually, when the U.S. and Canadian Government programmes were developed early in 1942, there were four engine-builders in Canada and ten in the U.S., all building the same design of engine to a total number approaching 2000.

As with other British designs, the British drawings were not immediately suitable for issuing to the U.S. and Canadian shops. British marine engine builders and other manufacturers in general leave many details off the drawings to shop practice—an arrangement which works out very well when the staff have grown up on the job, and where the whole unit is usually cast, machined, assembled, erected, installed and delivered under the one roof. For U.S. conditions, however, it was necessary to amplify and re-dimension the British plans in respect of tolerances, fits and clearances, degree of finish, fillets, &c., and also certain other modifications to meet U.S. standard flanges and standard fittings. Apart from these items and the use of U.S. threads, spanner sizes, &c., the main-engine design followed the British parent design. The Canadian engines in the above items generally follow British practice. Also the British practice is to include many items on the one tracing, and it was necessary to break these down into single-item plans.

The above process of "interpretation of British plans" was a very substantial item, and in the case of the main engine the 80 British working

plans were expanded into about 400. A similar proportion prevailed in other items, including hull plans.

The main boilers were of the three-furnace Scotch type to details as shown in Appendix B, and for the U.S. ships were built by one firm in the East and two on the West Coast.

The East firm was the American Locomotive Coy. of Schenectady, N. Y., whose contract for 90 boilers complete with fittings, mountings and superheaters, was placed in January, 1941. This firm had built several Scotch boilers some years previously but the present contract was their first serious experience with such boilers ; they had, however, built very many locomotives of the largest size up to 500 tons weight, and it was thought that such experience justified their being entrusted with the large marine-boiler contract—a procedure subsequently fully justified. The first boiler was completed on 28th April, 1941, and the last in September, 1941, the attained and maintained output being 25 boilers per month.

The West Coast boilers were ordered from two firms—The Western Pipe & Steel Company, Los Angeles, and Puget Sound Machinery Depot, Seattle (formerly Garrett & Shaeffer). This first named company had no previous experience with Scotch boilers, but was a well equipped plant accustomed to handle high-pressure equipment for the oil industry. The second company had built a large number of Scotch boilers in 1918-1921 and occasional boilers thereafter, and had the staff and equipment required for the job.

In the event the West Coast hulls made rapid progress—running several months ahead of contract schedule, and the West Coast boilers could not be accelerated quite sufficiently; the East Coast boilers, however, were ahead of schedule, and the first West Coast ship was, therefore, fitted with East Coast boilers, the boilers being transported 3000 miles by rail from Schenectady to San Francisco. After the first ship the West Coast boiler makers were able to meet all requirements of West Coast ships.

As with the hulls, the use of welding in the boiler construction was fully considered, along with other modifications to the British designs to meet the manufacturing facilities. In welding, perhaps the most important adoption was in the joint of the combustion-chamber wrapper plates to the tube and back plate where a butt weld with main run from outside and sealing run from inside was adopted; this procedure had the advantage of avoiding the rather specialized workmanship involved in the usual riveted lap joint; the wrapper plate butt was also welded, thereby avoiding the usual awkward three-ply joint. In some plants the wrapper plate was made in two portions with two welded butts for the purpose of facilitating manufacture. Figure 23 shows a set of chambers welded as above described.

Shells were riveted to British design in all cases with sealing welds at strap ends—the large size of shell presenting difficulties in welding and stress relieving. Combustion chamber stays were nutted inside except in the case of lower rows in way of curvature of wrapper plate; in this locality, to avoid the use of bevelled washers, the stay end was welded to the wrapper plate giving a pan-head finish. In some Canadian boilers unscrewed blower tubes were fitted, the tubes being welded at ends to plates. In some boilers, where the end plates or heads were in two portions, the seam was welded in lieu of lap riveting—this construction avoided the awkard three-ply joint in the usual construction.

An interesting situation developed in connection with the U.S. method of flanging end plates, the flanging being carried out by a "spinning" process, as described below:

The end plate, about 17 feet in diameter, is heated to the flanging temperature and placed on a horizontal face plate about 12 feet diameter, and

is held thereto by a hydraulically operated upper face plate of rather less diameter than the lower face plate.

Towards the rim of the end plate are two rollers—the inner and outer; the inner roller has a vertical axis and is adjustable radially and vertically and has its edge of the same radius as that required in the flanged plate. The outer roller has its axis capable of angular adjustment and is also adjustable radially.

The end plate is rotated at about 45 to 50 revolutions per minute and is first centered by means of the other roller, and is thereafter finally held central by the upper face plate.

The two rollers are now manipulated so as to give the required flanging —an operation carried out in one heat and taking 10-12 minutes.

Such machines were installed at the steel works and the end plates were delivered to the boiler shops in the flanged conditions. End plates flanged in this manner have flanges very true in the cylindrical sense and avoided the rather specialized workmanship involved by the usual British method of "local" flanging. Such an operation, however, requires a complete disc of uniform thickness, whereas the Scotch-boiler design demands two thicknesses of end plate—in this case 1 7/16-inch steam space and 31/32-inch in lower portion.

The following methods were used to meet the above requirements:

(1) Complete 1 7/16-inch end plate spun and subsequently two segments cut off to form two steam-space portions, the material between segments being reject.

Two complete 31/32-inch end plates spun and segments cut off to form lower portion of end plate—the smaller segments being reject and the top and bottom portions of respective plates riveted or welded together to form complete end plates.

This method involves considerable rejection of material.

(2) Two complete 1 1/32-inch end plates spun and 1 1/32-inch doubling plate riveted and seal welded to steam space portion of end plate.

(3) One complete 1 7/16-inch end plate spun and cut into two segments, the smaller segment, A, becoming the front upper portion and the larger segment, B, becoming the back upper plate. One complete 31/32-inch end plate spun and cut into two segments, the smaller segment, C, becoming the back lower portion. Segments, A.C. and B.D. welded together, the joint being horizontal, and at the front between the top row of tubes and lower row of steam-space stays; at the back the joint is between 8th and 9th row of stays.

Figure 24 and Figure 25 show the front and back of such a boiler; at the time of photographing the boiler was under a 220 pound steam-pressure test —this being locomotive practice which the makers preferred to adhere to.

In general, in the U. S. the West Coast boiler makers worked to scheme (2) above, and the East Coast makers to scheme (1) and latterly scheme (3) above.

In Canada the main boilers were built by four firms, namely Dominion Bridge Company (Montreal and Vancouver); John Inglis & Company, Toronto; Vancouver Iron Works, Vancouver. These firms all had, to a greater or less extent, previous experience with the manufacture of Scotch boilers and the boiler end plates were, as in the U.S. boilers, spun and ends made by scheme (1) above, and combustion chambers were mostly welded as described above. Messrs. Inglis, however, fitted riveted combustion chambers and end plates in accordance with scheme (2).

A difference between the U.S. and Canadian boilers is that the mountings in the former are to U.S. standard flange tables, whereas the latter are to British standards.

All boilers, U.S. and Canadian, are fitted with smoke-tube superheaters, giving the moderate steam temperature of 520 to 550 degrees F. This temperature was deemed preferable as it permitted the use of a superheater able to withstand considerable abuse. The manning of ships with engineers having experience with superheaters received consideration, and all ships had chief engineers or at least the second, with superheat experience.

In respect of deck and auxiliary machinery, as previously mentioned, the U.S. and Canadian ships differed. In each class, however, as with the main engines, a single design was adopted, and as the programme expanded other firms worked to the same design with the original maker as leading firm.

In the case of the U.S. ships, all were of U.S. make and the following principal items were of U.S. design:

Refrigerators, domestic and pantry.
Cargo winches.
Telemotors.
Lifeboats and engine.
Electric generating sets.
Forced draught fan and engine.
Main circulating pump and engine.
Feed pumps.
Ballast pump.
General service pump.
Distiller, evaporator and feed heater.

The following main items were of British design manufactured in the U.S.A.:

Main engine.
Main boilers.
Ash hoists.
Windlass.
Steering gear.

In Canada, apart from refrigerators, practically all the above items were of British design manufactured in Canada.

All above makers were able to meet their contract deliveries, and in the case of many firms to get into production very quickly on new products—it will, of course, be appreciated that the very rapid hull construction rate at the Richmond Shipyard had to be reflected all along the line, and it is very creditable to all makers of above equipment that no ship was delayed by delivery of any mechanical equipment.

INSTALLATION.

The fact of the hulls being welded had a number of reactions on the machinery, the following being the principal items of interest.

In the United States the general practice is to instal propelling machinery, including main engines, boilers and shafting, before launch; this practice enable the ships to be closed up before launch—a particularly desirable feature in the case of a welded ship. In general, the main engine and shafting will be temporarily positioned before launch and the chocks finally fitted when the hull is water borne.

Owing to the effect of contraction of the top side welds there is a pronounced tendency for the vessel as a whole to sag, and in addition contraction stresses can set up local deflections of the aft end; that is, the stern frame is liable to distortion apart from the hull structure—quite an important matter when boring out for the stern tube. The amount of hogging is of the order of one to two inches, and counteracted to a large extent by sagging

the keel blocks by an inch at each end. Alternatively, the tendency can be counteracted by leaving the upper shell and decks free in way of forward and aft hatches and leaving welding here to the last. Either way, however, the stern tube is best not finally sighted until the top side welding from midships to right aft is completed.

A second form of deflection was also experienced, particularly in the Richmond Yard, where it was found that the hull had a substantial variation of distortion during a twenty-four hour period—due presumably to the heating effect of the sun. This daily variation was probably more pronounced because the ends of the ship were more or less "afloat," as it were, due to the previously mentioned top-side contraction. Measurements disclosed that the stern-tube line was in a mean position as between 12 midnight and 2 a. m. and this time was adopted for final sighting through and marking off.

Another item where the welded hull called for special attention was in the fitting of chocks under the main engine. In a riveted ship the top plate in way of holding-down bolts remains very fair and level, permitting the chocks to be conveniently fitted from outboard of the bed-plate. In a welded ship, however, the top plate, due to contraction of welds at the top of floors and longitudinals, is not so regular and may present difficulty in the proper fitting of chocks. In general, and in the case of all British ships, the top plate could be levelled off in way of chocks by grinding locally so as to give the desirable parallelism or slight inward taper of the packing space. In some yards, however, where the distortion was more severe, the practice was adopted of welding pads, about ½-inch thick, in way of each holding down bolt and dressing off the top of pads.

As previously mentioned. in the U.S. British yards, as in all new U.S. yards, the machinery is as a rule installed before launch. It should be noted, however, that the yards were laid out with this in view, and the berth cranes were of a capacity to deal with machinery weights.

Each yard also had a large fitting out jetty with about 2500 feet water frontage well covered by four cranes, and with large machine and pipe shops, &c., conveniently located as shown in Figures 1 and 2.

Installation at the shipyard before launch is also facilitated in the U.S. by the capacity of rail transport from the engine and boiler works to the shipyards—the loading gauge being considerably greater than in this country.

Appendix A.

HULL SPECIFICATION.

Type: Open shelter-deck type with tonnage openings temporarily closed and bulkheads extended into the 'tween decks to enable the vessel to obtain 18 inches additional draught above the normal open shelter deck draught.

Hull form: Tank-test results of form adopted are shown in Figure 27.

Accommodation: Officers are berthed in a deck-house amidships and engineers alongside the engine casing. The crew accommodation is situated at the after end of the shelter deck and in a deck-house aft.

Accommodation is spacious and in accordance with the latest Ministry of War Transport recommendation, with steam heating throughout.

Deep tank: To be situated at the after end of the machinery space and designed for both water ballast and dry cargo.

Ballast: Total water ballast capacity 2120 tons.

Cargo capacity: 513,050 cubic feet, giving a stowage rate after allowing for 1100 tons of permanent bunkers of about 54¼ cubic feet to the ton on the deep draught.

Bunker capacity: 2400 tons total.

Winches: All to be 7 inches × 12 inches or equivalent with double gearing.

Windlass: 11 inches × 12 inches horizontal steam windlass to suit 2 5/16-inch cables, designed by Emerson, Walker, Ltd.

Derricks: Two 5 ton derricks at each hatch with additional heavy derricks.

Steering Gear: 8 inches × 8 inches Wilson-Pirrie type steering gear to plans supplied by Messrs. John Lynn & Co., Ltd.

Electrical installation: Complete installation in accordance with usual British practice and as per guidance plans by The Sunderland Forge & Engineering Co. Ltd., with two 15 Kw. steam generators 110 v. suitable for working at 100 pound steam pressure.

Stern frame: Open type, one piece, cast steel.

Rudder: Semi-balanced with forged-steel stock of American patent fabricated design.

Rudder carrier: In accordance with plans supplied by Taylor, Pallister & Co.

Fire extinguishing: Steam smothering throughout.

Galley range: Coal burning.

Domestic refrigerator: Having meat room of 350 cubic feet and vegetable room of 250 cubic feet capacity.

Lifeboats: Steel boats operated by mechanical davits.

Appendix B.

Outline Machinery Specification Applicable to Both U.S. and Canadian Ships Except Where Noted.

Main engine: Triple expansion with cylinders 24½ inches—37 inches—70 inches × 48-inches stroke developing 2500 Ihp.

Steam conditions: 220 pound boiler temperature and 550 degree V. steam temperature.

Valves: H.p. piston valve, m.p. and l.p. balanced slide valves.

Reversing gear: "All round" Stephenson link.

Stuffing boxes: H.p., m.p. and l.p. piston and all slide rods fitted with U.S. Metallic Packing, "King Tandam" type.

Piston packing: H.p. piston valve, h.p. and m.p. pistons fitted with "Lockwood and Carlisle" type rings ; l.p. piston fitted with plain ring and coach springs.

Crankshaft: Canada : two-piece fully built of steel forgings. U.S. : as above or one-piece solid forging.

Air pump: Edwards type driven from l.p. crosshead.

Condenser: Pear shaped 3000 square feet surface, aluminum brass tubes with screwed ferrules and linen packing.

Thrust block: Canada : Mitchell type standard design. U.S. : Kingsbury type interchangeable as complete unit with above.

Propeller shaft: Ingot steel continuous centrifugally cast liner.

Propeller (working): Solid bronze aerofoil sections variable pitch 18 feet 6 inches diameter, 16 feet 0 inches nominal mean pitch, 117 square foot surface.

Propeller (spare). Cast iron as above.

All propellers and shafts bored, turned and key-ways cut to solid gauges made by one maker.

Circulating pump: Centrifugal driven by enclosed single-cylinder engine with capacity of 3650 U.S. gallons per minute against 25 foot total head.

In U.S. ships centrifugal and fan engine interchangeable.

Feed pumps:

Two vertical simplex with float control.
U.S. pumps 12 inches—8 inches × 24 inches Worthington.
Canadian pumps 8 inches—10½ inches × 22 inches Weir design.

Ballast pump:

One vertical duplex.
U.S. pumps 10 inches—11 inches × 12 inches Worthington.
Canadian pumps 10 inches—12 inches × 10 inches Carruthers design.

General service pump:

One vertical duplex.
U.S. Pumps 9 inches—6 inches × 10 inches Worthington.
Canadian pumps 9 inches—6 inches × 10 inches Carruthers design.

Insulation:

2 inches thick on main steam pipes.
1 inch thick on auxiliary steam pipes.
1 inch thick on auxiliary exhaust pipes.
3 inches thick on boilers.

Evaporator: One of 25 tons per day capacity.

Auxiliary condenser: Atmospheric of 600 square foot surface, tubes as for main condensers.

Feed heater: Surface type in feed pump discharge taking exhaust steam from all auxiliaries.

Feed filters: Gravitation type in feed pump suction and pressure type in feed pump discharge.

Ash hoist: Crompton type self tipping.

Boilers: Three Scotch type each 14 feet 9 inches external diameter by 11 feet 9 inches external length and total heating surface of 7140 square feet, 220 pounds per square inch pressure, smoke-tube superheaters in 3-inch tubes giving about 550 degrees F. total temperature.

Three furnaces per boiler fitted for coal-burning with Howden's forced draught.

Forced draught fan: One, driven by single-cylinder enclosed engine.

Materials: In Canada: closely followed British practice. In U.S.: a number of modifications to meet U.S. practice.

Drawings: Each ship supplied with set of blue prints and instruction books covering essentials of all important equipment.

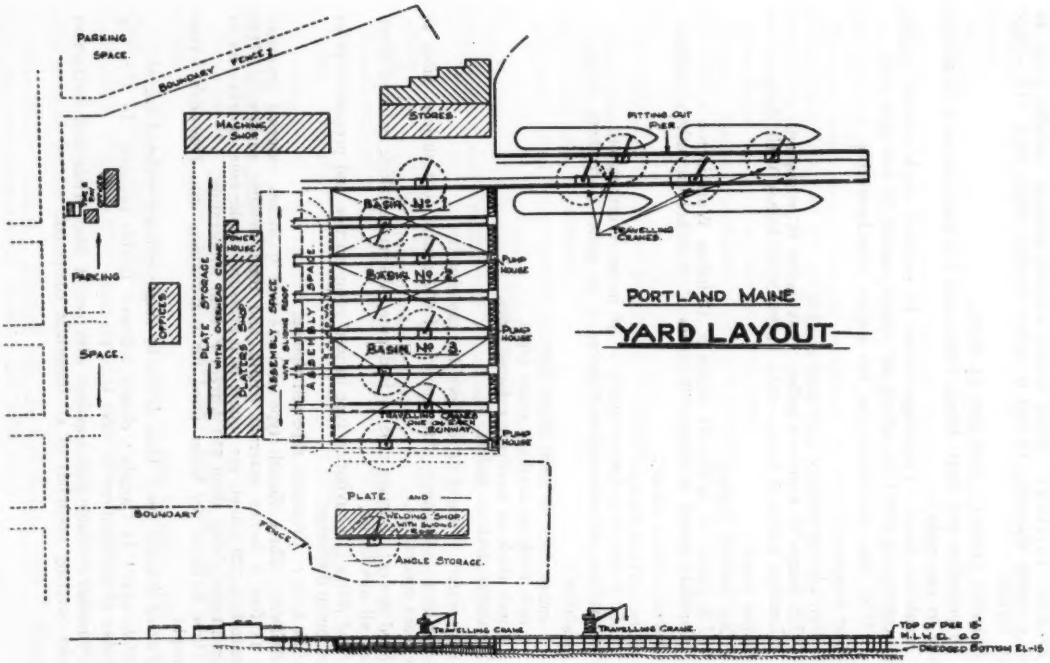
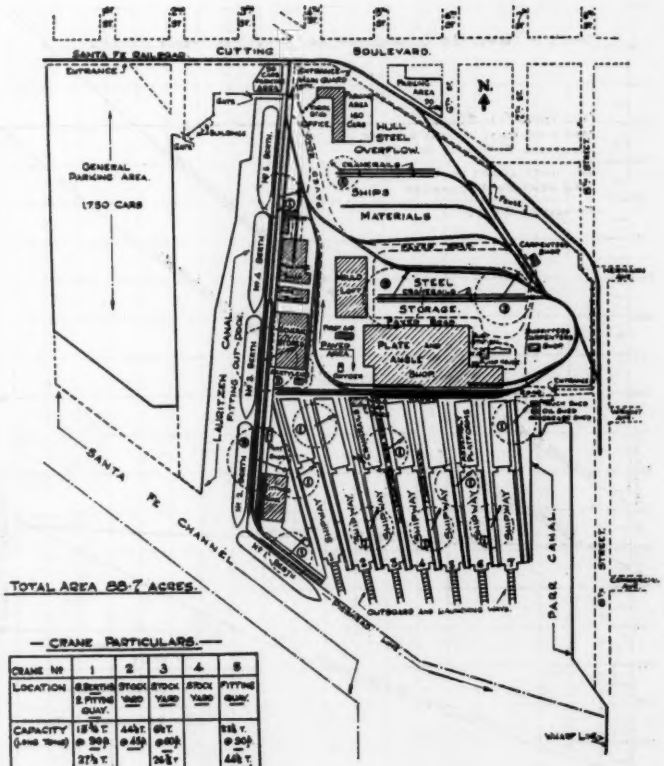

PARKING SPACE.
BOUNDARY FENCE
MACHINE SHOP
STORES.
FITTING OUT PIER
TRAVELLING CRANES.
BASIN No. 1
BASIN No. 2
BASIN No. 3
PUMP HOUSE
PUMP HOUSE
PUMP HOUSE
POWER HOUSE
PLATE STORAGE WITH OVERHEAD CRANE
PLATERS SHOP
ASSEMBLY SPACE WITH SLIDING ROOF
ASSEMBLY SPACE
TRAVELLING CRANES ONE ON EACH RUNWAY
OFFICES
PARKING SPACE.
PLATE AND WELDING SHOP WITH SLIDING ROOF
ANGLE STORAGE.
BOUNDARY FENCE
PORTLAND MAINE
YARD LAYOUT
TRAVELLING CRANE.
TRAVELLING CRANE.
TOP OF PIER 15'
M.L.W. EL. 0.0
DREDGED BOTTOM EL.-15

FIGURE 1.



— CRANE PARTICULARS.—

CRANE No.	1	2	3	4	5
LOCATION	1. BERTHS 2. FITTING QUAY.	STOCK YARD	STOCK YARD	STOCK YARD	FITTING QUAY.
CAPACITY (LONG TONS)	18½ T. @ 30ft. 27½ T. @ 30ft. 44½ T. @ 45ft.	44½ T. @ 45ft.	6½ T. @ 80ft. 26½ T. @ 35ft.		22½ T. @ 30ft. 44½ T. @ 45ft.
HOISTING MOTOR	150 H.P.	150 H.P.	100 H.P.	100 H.P.	200 H.P.

FIGURE 1.

FIGURE 2.—TODD—CALIFORNIA SHIPBUILDING CORP. YARD LAYOUT.

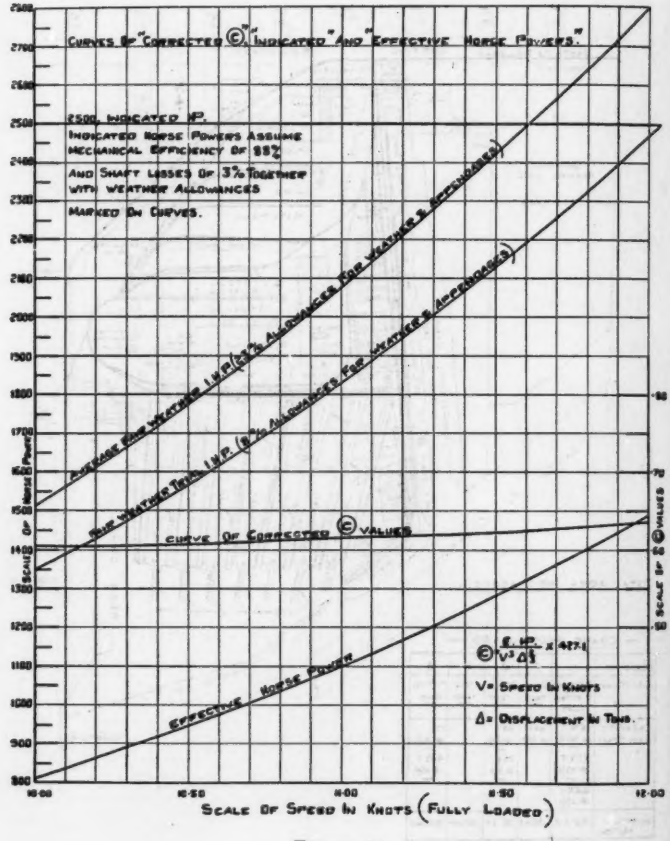

Curves Of "Corrected ©" "Indicated" And "Effective Horse Powers."
2500 Indicated HP.
Indicated Horse Powers Assume Mechanical Efficiency Of 88%
And Shaft Losses Of 3% Together With Weather Allowances Marked On Curves.
Average Fine Weather I.H.P. (12½% Allowances For Weather & Appendages)
Fine Weather Trial I.H.P. (9% Allowances For Weather & Appendages)
Curve Of Corrected © Values
Effective Horse Power
© = S.HP. / V³ Δ⅔ × 427.1
V = Speed In Knots
Δ = Displacement In Tons.
Scale Of Horse Power
Scale Of © Values
Scale Of Speed In Knots (Fully Loaded.)

FIGURE 27.

SCALE OF 50 VALUES =
25
0

MIDSHIP SECTION.

CLASS – LLOYDS REGISTER OF SHIPPING + 100 A.1. WITH FREEBOARD.
SCANTLINGS SUITABLE FOR A MOULDED DRAUGHT OF 26'-10" WHICH IS 18 INCHES IN EXCESS OF THAT FOR A C.S.S. VESSEL.

PRINCIPAL DIMENSIONS.

LENGTH B.P.	416'-0
BREADTH MOULDED	56'-0"
DEPTH MLD. TO UPPER DK.	37'-4
DEPTH MLD. TO 2ND DK.	28'-7
DEPTH TO KEELSON.	11-14

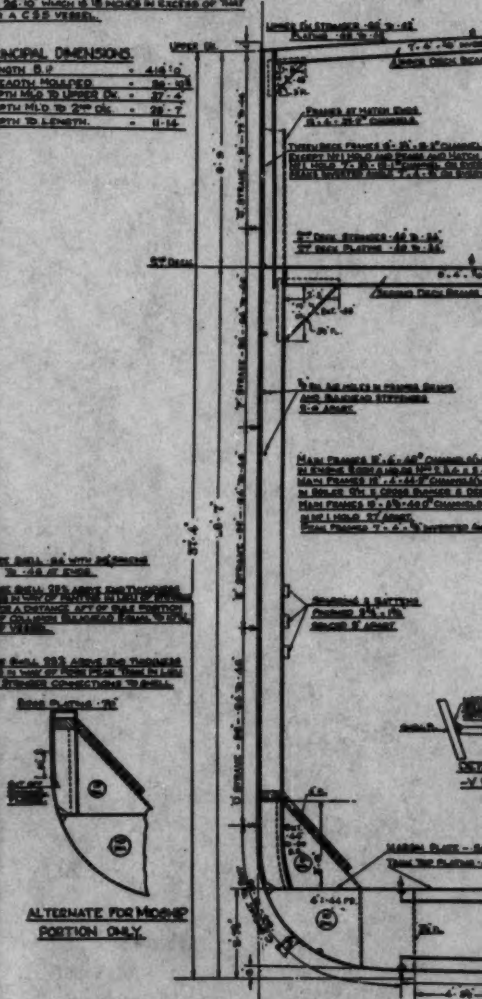


Plate 1

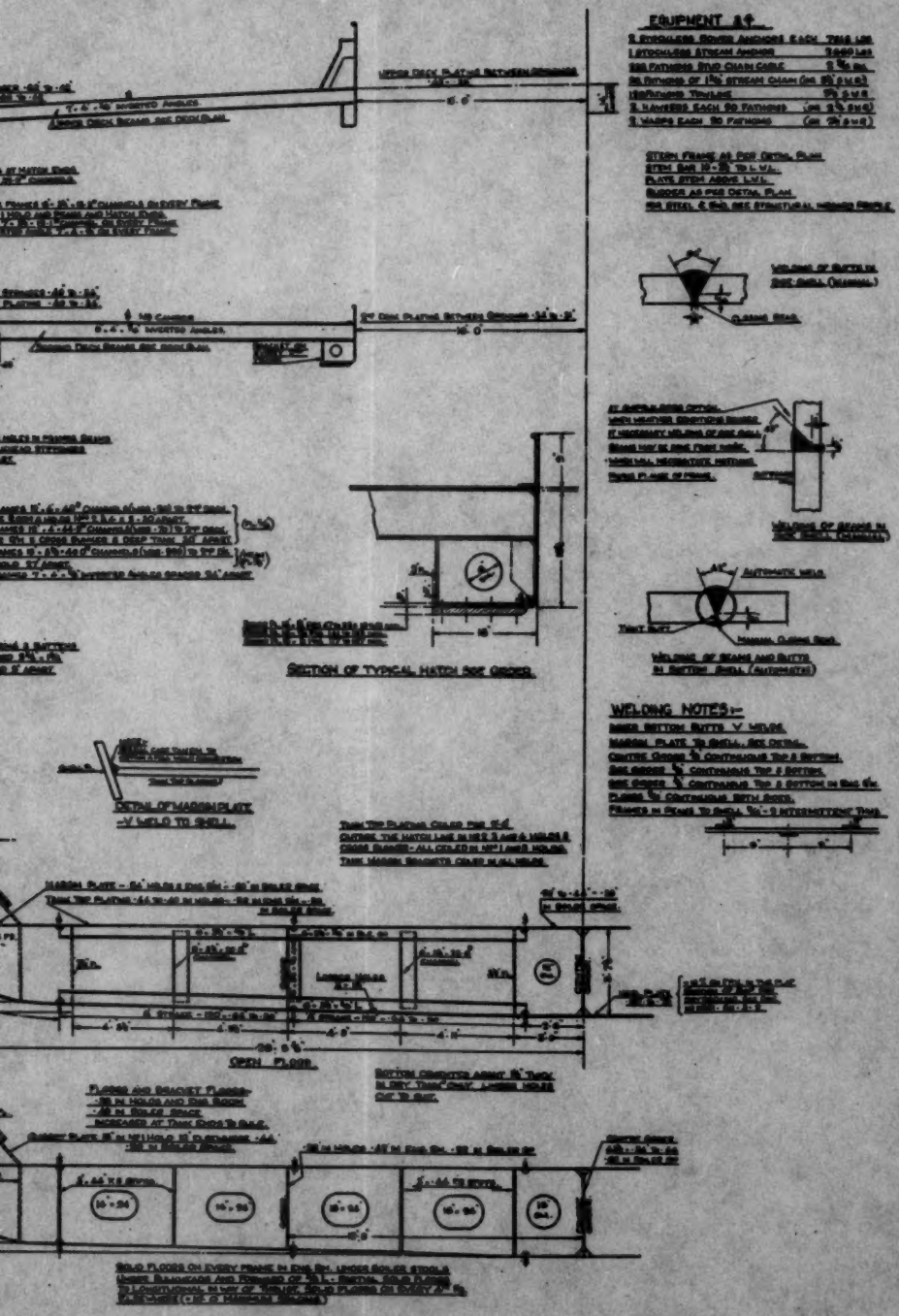
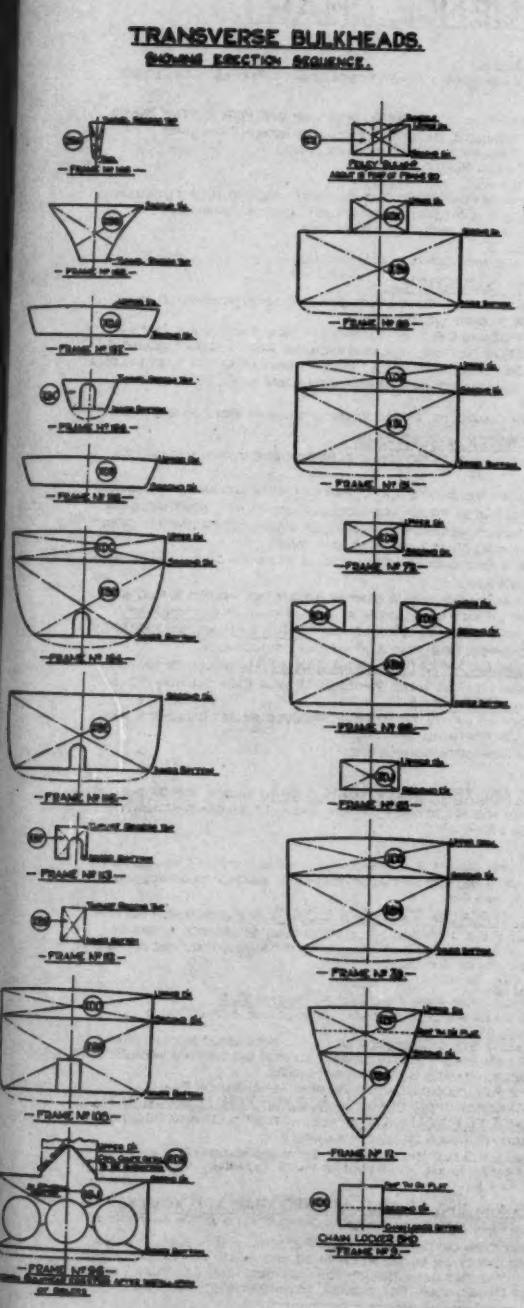
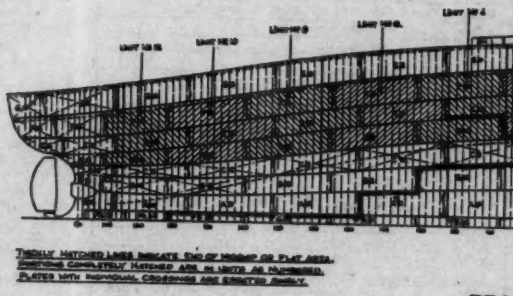


FIGURE 8.





THICKLY HATCHED LINES INDICATE END OF HOOKUP OR FLAT AREA.
DIRECTIONS CORRECTLY HATCHED ARE IN UNITS AS NUMBERED.
PLATES WITH INDIVIDUAL CROSSINGS ARE ERECTED ASSLY.

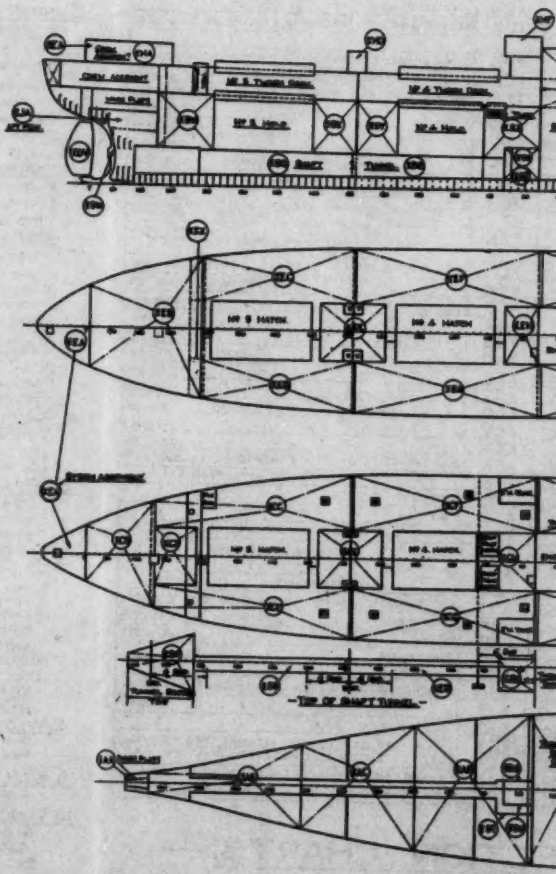
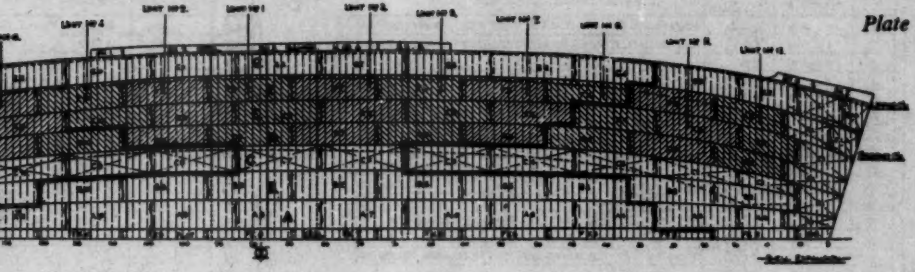


FIGURE 6.

SHELL EXPANSION.

SHOWING ERECTION SEQUENCE.

Plate 3



PROFILE DECKS & TANK TOP

SHOWING ERECTION SEQUENCE.

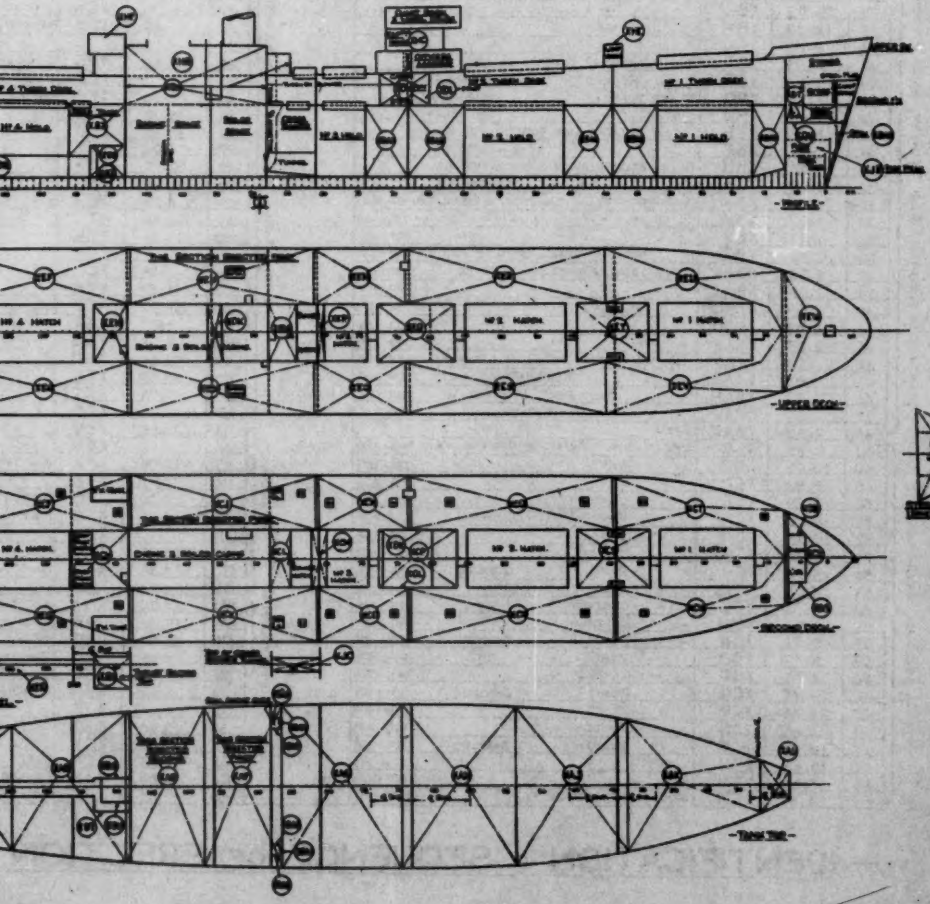


Plate 4

Group	LINE	WEIGHT OF SECTIONS IN TONS (2240#)	ERECTION SECTION SYMBOL	DESCRIPTION & LOCATION OF ERECTION SECTION.
DOUBLE BOTTOM STRUCTURE	1	.64	XAA	RIDER PLATE INCL. FLOORS & VERT KEEL FRAMES 162-166
	2	16.79	XAB	DBLE BTM INCL: FLOORS, T. TOP PLTS, VERT KEEL & SIDE GDRS 140½-162
	3	26.15	XAC	" " " " " " " " " FRS 124½-140½
	4	34.57	XAD	" " " " " " " " " 108½-124½
	5	36.07	XAE	" " " " " " " " " 97½-108½
	6	33.47	XAF	" " " " " " " " " 86½-97½
	7	38.11	XAG	" " " " " " " " " 69½-86½
	8	35.70	XAH	" " " " " " " " " 55½-69½
	9	38.02	XAJ	" " " " " " " " " 37½-55½
	10	30.05	XAK	" " " " " " " " " 16½-37½
	11	3.69	XAL	" " " " " " " " " 12-16½
BULKHEADS & STRUCTURES BETWEEN INNER BOTTOM & SECOND DECK	12	.51	XBA	AFT PEAK BHD 166 - KEEL TO TUNNEL RECESS TOP.
	13	3.67	XBB	" " " 162 - TUNNEL RECESS TOP TO 2ND DK.
	14	.94	XBC	TRANS " 156 INNER BOTTOM TO TUNNEL RECESS TOP
	15	12.68	XBD	" " 134 " " " 2ND DK.
	16	17.77	XBE	" " 116 " " " " "
	17	.77	XBF	" " 113 " " " THRUST RECESS TOP
	18	.83	XBG	" " 112 " " " " " "
	19	16.60	XBH	" " 108 " " " 2ND DK.
	20	4.94	XBJ	TRANS BHD 96 (SPECTACLE SCREEN) INNER BTM TO 2ND DK. ERECTED IN SEVERAL SECTIONS AFTER INSTALL OF BOILERS.
	21	9.92	XBK	TRANS BHD 88 INNER BOTTOM TO 2ND DK.
	22	15.23	XBL	" " 81 " " " " "
	23	14.72	XBM	" " 68 " " " " "
	24	9.57	XBN	" " 39 " " " " "
	25	4.99	XBO	FORE PEAK BHD 12 KEEL TO 2ND DK.
	26	2.64	XBP	TUNNEL RECESS TOP FRAMES 156-166.
	27	11.17	XBQ	SHAFT TUNNEL " 134½-156
	28	9.57	XBR	" " " 113-134½
	29	1.49	XBS	THRUST RECESS SIDE PORT FRS. 108-113
	30	1.31	XBT	" " " STBD " 108-113.
	31	1.03	XBU	THRUST RECESS LONGL BHD STARD 108-112.
	32	1.08	XBV	" " TOP FRS. 108-113
	33	2.55	XBW	LONGL ℄ BHD & PILLAR - TUNNEL TOP TO 2ND DK. FRS. 134-162.
	34	1.97	XBX	" " " " " " " " " 134-140
	35	1.97	XBY	" " " " " " " " " 108-134
	36	2.54	XBZ	" " WASH BHD - TUNNEL TOP TO 2ND DK. " 108-116
	37	2.96	XBAA	" ℄ BHD. & PILLAR INNER BTM TO 2ND DK. " 68-74
	38	3.91	XBAB	" " " " " " " " " 60-68
	39	3.59	XBAC	" " " " " " " " " 39-46
	40	3.23	XBAD	" " " " " " " " " 33-39
	41	2.41	XBAE	" " " " " " " " " 12-18.
	42	.68	XBAF	COAL SHOOT SIDE-PORT FRAMES 86½-88
	43	.68	XBAG	" " " STARBOARD. " " 86½-88
	44	.37	XBAH	" " END - PORT FRAME 88
	45	.37	XBAJ	" " " STARBOARD. " 88
	46	2.50	XBAK	STEM.
SECOND DECK.	47	7.85	XCB	2ND DK PLTS INCL. BEAMS & GIRDERS FRS. 161½-173½
	48	16.43	XCC	" " (PORT) " " " " 133½-161½
	49	15.50	XCD	" " (STBD) " " " " 133½-161½
	50	3.69	XCE	" " (CENTRE) " " 129½-138½
	51	16.87	XCF	" " (PORT) " " GIRDERS " 107½-133½
	52	16.53	XCG	" " (STBD) " " " " 107½-133½
	53	3.59	XCH	" " (CENTRE) " " 108-116½
	54	13.53	XCJ	" " (PORT) " " GIRDERS " 91½-107½
	55	13.53	XCK	" " (STBD) " " " " 91½-107½
	56	1.74	XCL	" " (CENTRE) " " 85-88
	57	1.53	XCM	" " (CENTRE) " " 80-82
	58	9.01	XCN	" " (PORT) " " GIRDERS " 69½-91½
	59	8.77	XCO	" " (STBD) " " " " 69½-91½
	60	4.75	XCP	" " (CENTRE) " " 61½-72½
	61	24.40	XCQ	" " (PORT) " " GIRDERS " 39½-69½
	62	24.36	XCR	" " (STBD) " " " " 39½-69½
	63	4.67	XCS	" " (CENTRE) " " 34½-44½
	64	16.00	XCT	" " (PORT) " " GIRDERS " 12½-39½
	65	15.59	XCU	" " " " " " " " 12½-39½
	66	3.57	XCV	" " " " " " " STEM-12½
	67	4.31	XCW	FORWARD TWEEN DK FLAT STEM-12

Group	LINE	WEIGHT OF SECTIONS IN TONS (2240#)	ERECTION SECTION SYMBOL	DESCRIPTION & LOCATION OF ERECTION SECTION.
BULKHEAD STRUCTURES BETWEEN 2ND DK & UPPER DK.	68	2.59	XDA	TRANS BHD 157 2ND DECK TO UPPER DE[CK]
	69	2.78	XDB	" " 155 " " " "
	70	3.11	XDC	" " 134 " " " "
	71	2.70	XDD	" " 108 " " " "
	72	2.21	XDE	FIDLEY BHD 90 ABOVE 2ND DK.
	73	2.40	XDF	" " 86 " " "
	74	2.57	XDG	TRANS BHD 81 2ND DECK TO UPPER DEC[K]
	75	2.35	XDH	STORE ROOM END 72 2ND DK TO UPPE[R]
	76	1.35	XDJ	" " " 65 " " " "
	77	.94	XDK	" " SIDE - PORT FRS. 65-72 2N[D]
	78	.96	XDL	" " " - STARD " " " "
	79	1.06	XDM	TRANS BHD 66 - PORT 2ND DK TO UPPER
	80	1.14	XDN	" " 66 STARD " " " "
	81	4.60	XDO	" " 39 " " " "
	82	3.89	XDP	" " 12 " " " "
	83	1.43	XDQ	CHAIN LKR END FR 9 - BTM OF CHN LKR TO FORD T
	84	.52	XDR	" " SIDE - PORT - FRS 9-12 BTM OF CHN LKR TO
	85	.52	XDS	" " " STARD " " " " " "
	86	.42	XDT	" " ℄ BHD FRS 9-12 " " " " "
	87	1.49	XDU	" " BOTTOM " 9-12 UNDER 2ND
	88	7.21	XDV	RUDDER
	89	11.75	XDW	STERN FRAME.
	90	32.49	XDX	MACHY CASING BHD P&S COMPLETE FRS 88-10[?]
	91			
	92	4.26	XDZ	C.LINE PILLARS & STRUTS - 2ND DK TO UPPER DK
UPPER DECK.	93	10.72	XEA	STERN ASSEMBLY, INCL: TRANSOM, DKS & WEB & CANT-F[R]
	94	16.80	XEB	UPPER DK PLTS INCL. BEAMS & GIRDERS F[RS]
	95	15.77	XEC	" " " (PORT) " " " "
	96	15.35	XED	" " " (STBD) " " " "
	97	4.06	XEE	" " " (CENTRE) " "
	98	22.19	XEF	" " " (PORT) " " " GIRDERS
	99	21.49	XEG	" " " (STBD) " " " "
	100	2.05	XEH	" " " (CENTRE) " "
	101	18.49	XEJ	" " " (PORT) " " " GIRDERS
	102	18.49	XEK	" " " (STBD) " " " "
	103			
	104	2.05	XEM	UPPER DK PLTS (CENTRE) INCL: BEAMS FR[S]
	105	11.57	XEN	" " " (PORT) " " & GIRDERS "
	106	11.05	XEO	" " " (STBD) " " " "
	107	1.07	XEP	" " " (CENTRE) " " "
	108	5.36	XEQ	" " " (CENTRE) " " "
	109	24.41	XER	" " " (PORT) " " " GIRDERS "
	110	23.69	XES	" " " (STBD) " " " " "
	111	4.78	XET	" " " (CENTRE) " " "
	112	18.19	XEU	" " " (PORT) " " - GIRDERS "
	113	18.58	XEV	" " " (STBD) " " " " "
	114	8.42	XEW	" " " " " " " "
FRAMING.	115	176.08	XFA	MAIN FRAMES BELOW 2ND DK WITH BRACKETS & G[IRDERS]
	116	20.02	XFB	" " 2ND TO UPPER DK WITH BRACK[ETS]
	117	2.70	XFC	AFT. PEAK FRAMES
	118	6.01	XFD	FORE " "
SHELL.	119	575.97	XGA	SHELL PLATING (AUTOMATIC WELDING)
	120		XGB	" " (MANUAL WELDING)
	121	1.33	XGC	BILGE KEEL - PORT.
	122	1.33	XGD	" " - STARBOARD.
SUPERSTRUCTURE.	123	14.60	XHA	AFT. DK HOUSE ASSEMBLY - ABOVE U. DK FRS.
	124	15.81	XHB	DECK HOUSE " " " " "
	125	48.95	XHC	BRIDGE " " " " "
	126	3.89	XHD	PAINT STORE " " " FR.
	127	3.89	XHE	LAMP ROOM " " " "
	128	6.45	XJA	STRINGERS AFT OF FR 162 WITH FLOORS & WASH PLTS
	129	6.64	XJB	" FORD " 12 " " " " "
	130	3.20	XJC	CROSS BUNKER TUNNEL.
	131	2.70	XCX	2ND DK PLTS. (CENTRE) INCL. BEAMS FRS 1[?]
	132	.17	XEX	UPPER DK GIRDER BETWEEN FRAMES 1[?]
	133	6.08	XAM	FOUNDATIONS FOR SHAFT BEARINGS IN SHAFT T[UNNEL]
	134		XHF	BOAT DECK HOUSE FRAMES 10[?]

—IDENTIFICATION & SEQUENCE OF ERECTION CHARTS.—

FIGURE 7.

SEQUENCE CHART.

1. FLAT OF BOTTOM SHELL.

(a) FLAT KEEL, STRAKES A & B. PORT & STAR?, TO BE LAID IN POSITION & TACK WELDED AT SEAMS & BUTTS.

(b) BEGINNING AT AFT END OF FLAT OF STRAKE A. START WELDING PORT & STAR? SEAMS JOINING FLAT KEEL TO STRAKE A, USING TWO MACHINES WORKING FORWARD SIMULTANEOUSLY TO FORWARD END OF FLAT PLATING.

(c) WELD BUTTS OF FLAT KEEL PLATE.

(d) WELD BUTTS OF STRAKE A.

(e) BEGINNING AT AFT END OF FLAT OF STRAKE B, START WELDING PORT & STARBOARD SEAMS JOINING STRAKES A & B. USING TWO MACHINES WORKING FORWARD SIMULTANEOUSLY TO FORWARD END OF FLAT PLATING.

(f) WELD BUTTS OF STRAKE B.

(g) FLAT OF BOTTOM SHELL IS NOW COMPLETELY WELDED.

2. BOTTOM SHELL WITH CURVATURE.

(a) BOTTOM SHELL WITH CURVATURE FOR? & AFT OF FLAT BOTTOM SHOULD NOW BE LAID IN POSITION & TACK WELDED.

(b) MANUAL WELDING OF SEAMS & BUTTS WILL FOLLOW SAME PROCEDURE AS FOR MACHINE WELDING OF FLAT BOTTOM, IE. CORRESPONDING PORT & STAR? SEAMS & BUTTS WILL BE WELDED SIMULTANEOUSLY, EXCEPT THAT IN AFTER BODY WELDING SHOULD PROCEED IN AFT DIRECTION & IN FORWARD BODY SHOULD PROCEED IN FORWARD DIRECTION.

(c) BOTTOM SHELL IS NOW COMPLETE, READY TO RECEIVE INNER BOTTOM SECTIONS.

3. INNER BOTTOM ERECTION SECTIONS.

(a) SECTION XAF TO BE LAID IN POSITION & CENTRE GIRDER TACK WELDED TO FLAT KEEL.

(b) FLOORS SHOULD NOW BE WELDED TO FLAT OF BOTTOM, WITH WELDING AS CALLED FOR ON PLANS BEGINNING AT FR. 87 AND WORKING AFT - PORT & STBD WELDING SHOULD PROCEED SIMULTANEOUSLY. WELDING OF EACH FLOOR SHOULD START AT KEEL & WORK OUTBOARD, PORT & STARB AT SAME TIME.

(c) WELD CENTRE GIRDER & SIDE GIRDERS, WITH WELDING AS NOTED ON PLANS, BEGINNING AT FR. 87 AND WORKING AFT.

(d) SECTION XAE TO BE LAID IN POSITION & CENTRE GIRDER TACK WELDED TO FLAT KEEL.

(e) WELD ENDS OF CENTRE GIRDER & SIDE GIRDERS TO ENDS OF SAME ON SECTION XAF.

(f) REMAINDER OF WELDING SHOULD PROCEED AS FOR SECTION XAF, WORKING FROM FORWARD TO AFT END OF SECTION, PORT & STARB SIMULTANEOUSLY.

(g) SECTIONS XAG, XAD, XAC, XAH, XAB, XAJ, XAA, XAK & XAL SHOULD BE LAID IN POSITION IN ORDER NOTED. THE WELD PROCEDURE FOR EACH SECTION BEING SAME AS FOR SECTIONS XAF & XAE.

(h) WELDING OF ALL SECTIONS AFT OF FR. 87 MUST PROCEED IN AFT DIRECTION AND FORWARD OF FR. 87 IN FORWARD DIRECTION.

(j) INNER BOTTOM HAS NOW BEEN COMPLETED.

4. BULKHEADS.

(a) SECTIONS XBH, XBK, XBL, XBAF, XBAG, XBAH, & XBAJ UNDER 2ND DK SHOULD NOW BE ERECTED, TACK WELDED TO INNER BOTTOM, FAIRED & THEN CONTINUOUSLY WELDED TO INNER BOTTOM.

5. SHELL PLATING.

(a) STRAKES F, E & D, BETWEEN BULK?S 81 & 96 SHOULD NOW BE ERECTED WITH FRAMES TO 2ND DK & STRAKES F, E & D, OF SHELL PLATING SHOULD BE ERECTED IN SIMILAR MANNER AS NOTED IN PARAS 4 & 5 & ON COMPLETION OF SAME STRUCTURE SHOULD BE ATTACHED TO PL?S, THE BOTTOM END OF FRAMES BEING ONLY TACK WELDED TO INNER BOTTOM AT THIS TIME.

6 REMAINING BULKHEADS TRANS & LONGL BETWEEN INNER BOTTOM & 2ND DK & STRAKES F, E & D, OF SHELL PLATING SHOULD BE ERECTED IN SIMILAR MANNER AS NOTED IN PARAS 4 & 5 & ON COMPLETION OF SAME STRUCTURE SHOULD BE READY FOR ERECTION OF 2ND DECK

7 2ND DECK PLATING.

(a) SECTION XCJ TO BE ERECTED FIRST FOLLOWED BY SECTION XCK.

(b) SQUARE UP ENGINE & BOILER HATCH, PULL SHELL TO DECK LINE & TACK WELD.

(c) ADD SECTIONS XCL & XCM.

(d) WELD FRAMES TO INNER BTM & UNDERSIDE OF 2ND DK. THEN WELD BOTTOM BRACKETS TO FRAMES & INNER BTM, LONGL MARGIN GUSSETS TO BTM BRACKETS & INNER BOTTOM AND 2ND DK BEAM BKTS TO FRAMES IN THE ORDER NAMED.

(e) CONTINUOUS WELD 2ND DK TO SHELL WITH WELDING AS NOTED ON PLANS.

(f) PROCEED WITH THE ERECTION OF SECTIONS XCF, XCG, XCH, XCN, XCO, XCQ, XCR, XCP, XCC, XCD, XCE, XCT, XCU & XCS IN ORDER NOTED, FOLLOWING PROCEDURE NOTED IN PRECEEDING LINES (b) TO (e) INCLUSIVE.

8 WELD FLOORS TO SHELL PLATING BETWEEN FLAT BOTTOM & MARGIN PLATE - WELD SEAMS P & S OF STRAKES B & C. WELD MARGIN PLATE TO SHELL - WELD SEAMS P & S OF STRAKES C & D.

9. ERECT SECTIONS XBA, XBB, XDW, XJA, XCB, XBO, XBAK, XJB, XCV & XCX

IN ORDER NOTED. STRUCTURE SHOULD NOW BE COMPLETE TO 2ND DK, ALL FORE & AFT.

10. PROCEED WITH ERECTION OF TWEEN DK BULK?S & STRAKE G OF SHELL PLATING IN SAME MANNER OF ERECTION AS BETWEEN INNER BTM & 2ND DK - ERECT LONGL GIRDER 10'-0" OFF ℄ P & S BETWEEN BULK?S 156 & 157 SECTION XEX - THEN LAY IN SECTIONS OF UPPER DK WITH SAME PROCEDURE AS USED FOR 2ND DECK.

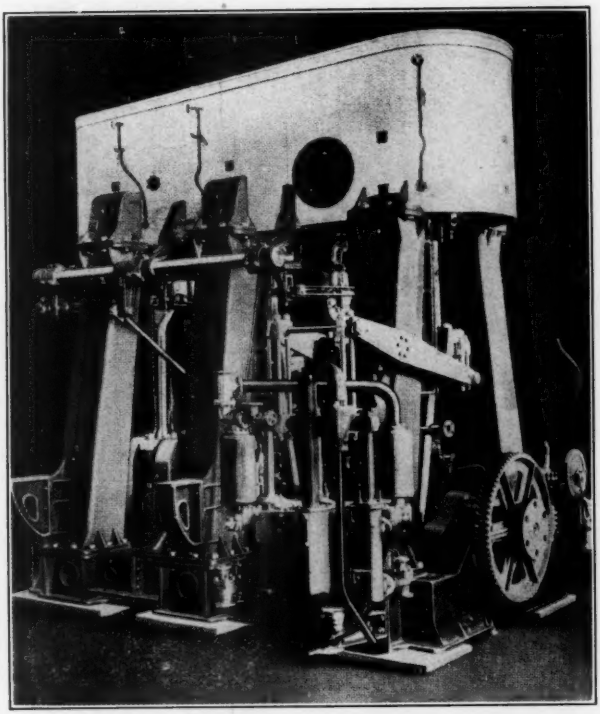


FIGURE 19.—MAIN ENGINE.

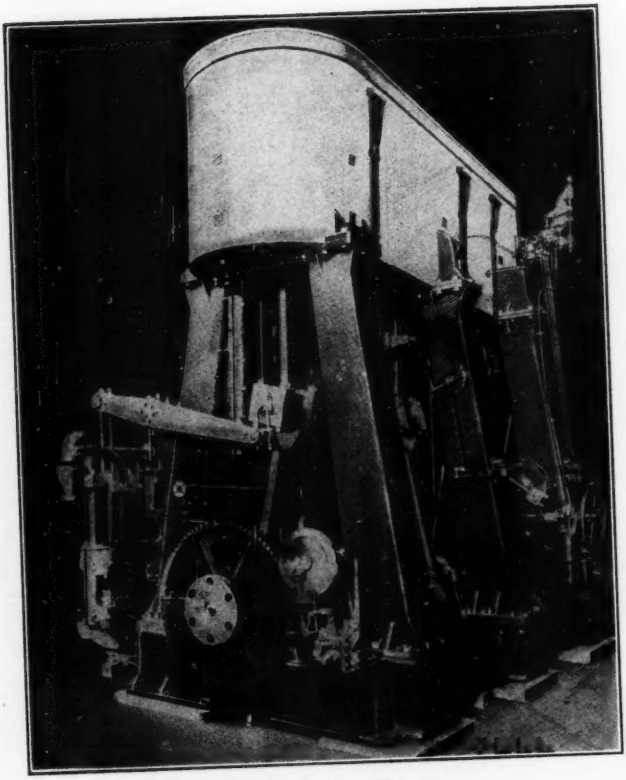


FIGURE 20.—MAIN ENGINE.

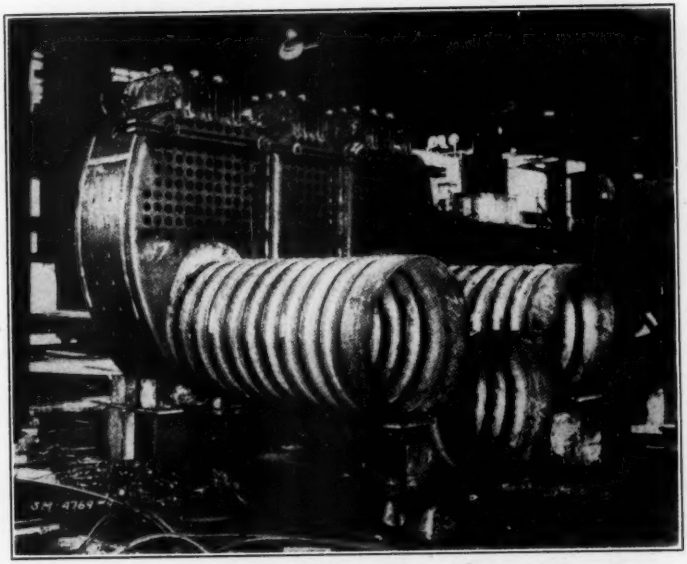


FIGURE 23.—COMBUSTION CHAMBER.

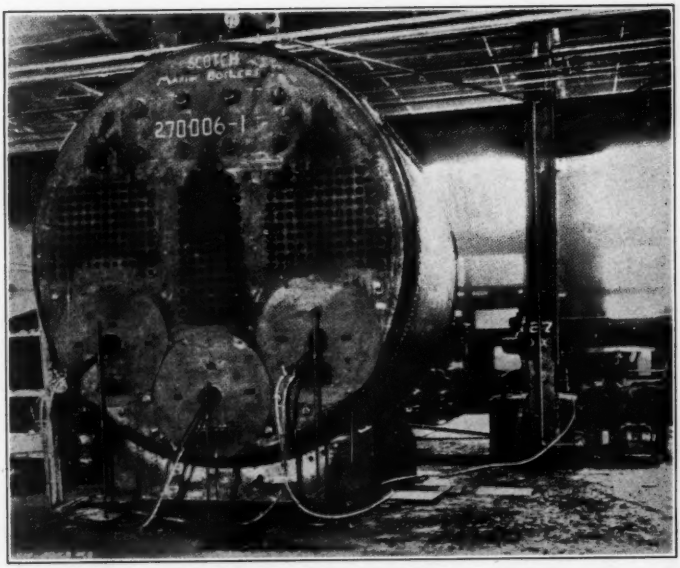


FIGURE 24.—BOILER FRONT.

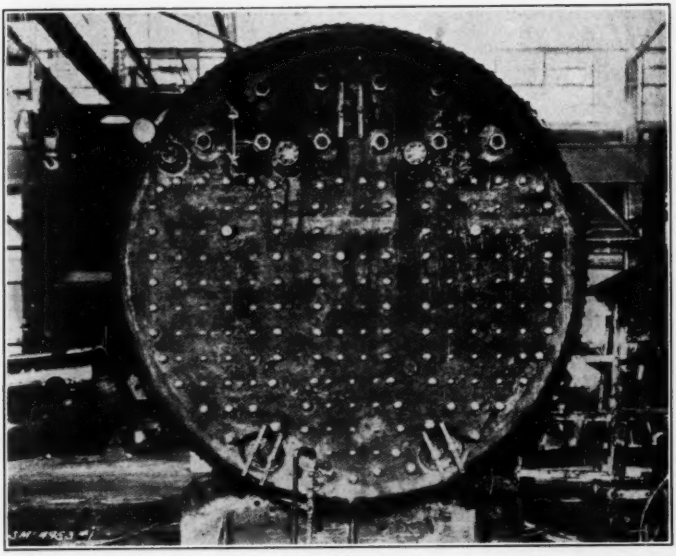


FIGURE 25.—BOILER BACK.

CAPACITY PLAN.

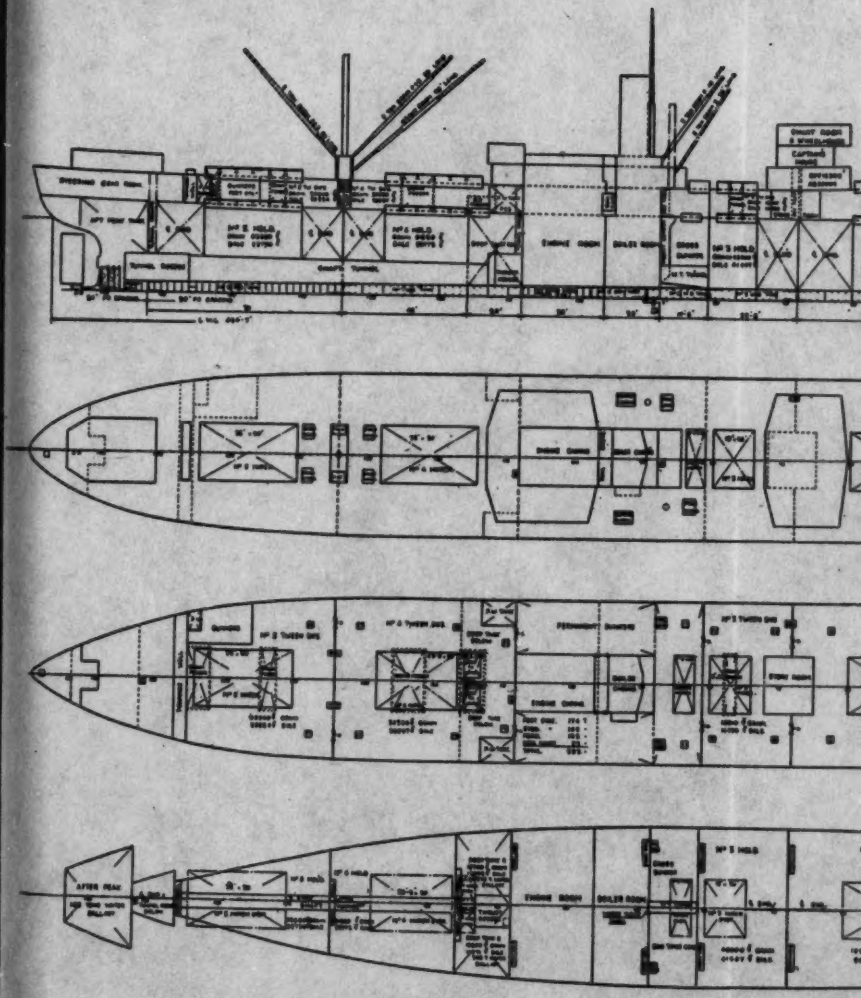


FIGURE 28.

Plate 5

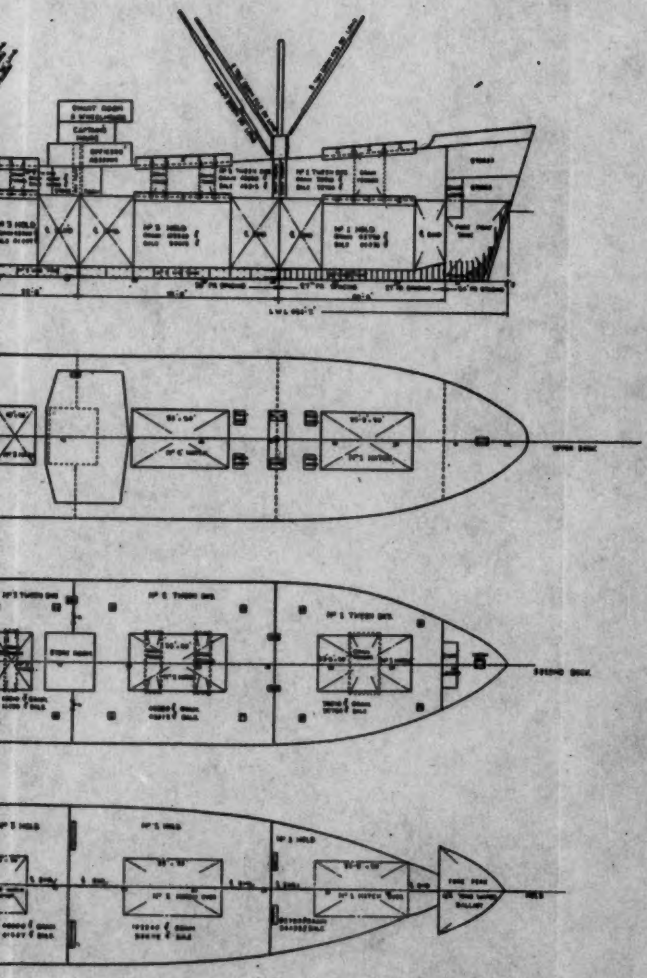


FIGURE 28.

EXHAUST PIPE PHENOMENA.

The following extracts of a paper read by G. F. Mucklow before the Manchester Association of Engineers on November 21, 1942, are reprinted from the January, 1943, issue of "The British Motor Ship." Mr. Mucklow is Professor of Mechanical Engineering in the University of Birmingham.

Introduction.

The object of the present Paper is to attempt some explanation of the laws governing the fluctuations of pressure which occur in the exhaust column of an internal combustion engine, and to outline the possibilities in regard to the use of these surge effects for scavenging purposes.

It has, of course, been common knowledge for many years that the performance of an engine may be favorably or adversely affected by the design of the exhaust system. Although the existence of some kind of pulsating flow in the exhaust pipe has long been realized, the more usual assumption has been that "back pressure," i.e., the resistance to the flow of the exhaust gases, was the controlling factor.

There have appeared on the market engines—such as the two-stroke Petter self-induction engine—in which scavenging is carried out without the need for any form of crankcase compression or separate scavenging pumps, evacuation of the exhaust products and induction of the fresh charge being effected solely by utilization of the pulsations of pressure in the exhaust pipe.

It is obvious that if the pulsations in a correctly proportioned exhaust system may be utilized to advantage the effects of an incorrectly designed system may be equally harmful. There is, in fact, no doubt that in many cases where obscure and apparently inexplicable engine trouble has been experienced the root cause has lain in an unsuitable exhaust system.

Figure 1 illustrates the effects on engine performance of unfavorable exhaust conditions.

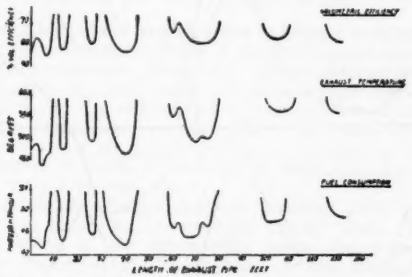


Figure 1.—Single-cylinder Two-stroke Engine. Crankcase Scavenge. Plain Exhaust Pipe.

In addition to effects produced by vibrations in the exhaust column, favorable or adverse effects on performance may result also from pulsations in the induction column, and the provision of a suitable ramming pipe may result in an increase of power of as much as 20 per cent.

For both the induction and the exhaust columns the basic laws governing the fluctuations of power are the same and it is thus of some importance that these laws should be well understood.

Origin of Pressure Fluctuations.

In a four-stroke engine running in the normal manner the fluctuations of pressure in the exhaust pipe originate from two separate causes. Thus on the opening of the exhaust valve the rush of escaping gas gives rise to a pulse of pressure in the port. This is followed after a short interval by a second pulse due to the motion of the piston on the exhaust stroke. In the two-stroke engine this second pressure pulse is of course absent and the vibrations in the exhaust column are produced by the single pulse only following the opening of the exhaust port.

A convenient method of studying the behavior of these pulsations is by the examination of indicator diagrams taken from a single-cylinder four-stroke engine under motoring conditions, since in such circumstances only the controlled pulse of pressure due to piston motion is present and the interval between successive pulses is double that in the case of a two-stroke engine at the same speed.

Figure 2 shows typical indicator diagrams of cylinder and exhaust port pressures from the four-stroke single-cylinder unit referred to.

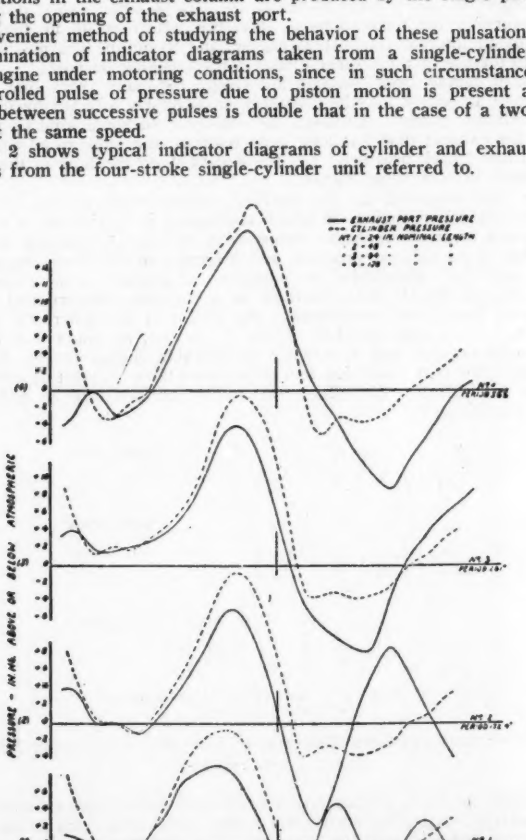


Figure 2.—Single-cylinder Four-stroke Unit (Motored). Typical Indicator Diagrams.

The pressure in the port rises to a maximum late in the exhaust stroke and then falls against below atmospheric in the neighborhood of T.D.C. A vacuum loop is thus formed of which position and duration depend on the engine speed and the dimension of the exhaust pipe, and it is obvious that the occurrence of this vacuum loop in relation to the points of inlet valve opening and exhaust valve closure will materially influence the scavenging and charging of the cylinder.

When the exhaust valve has closed, the ensuing fluctuations correspond to the natural free vibration in a pipe with one closed and one open end, though with long pipes distortions occur due to the presence of the residual wave from previous cycles. It is also noticeable that under all conditions the changes of pressure in the cylinder during the exhaust stroke follow, and are governed by, the fluctuations of pressure in the port.

The pressure fluctuations originate from the motion of the piston on the exhaust stroke which produces a fundamental pulse of pressure in the port. This disturbance travels forward through the gas in the exhaust pipe with the velocity of sound and on arrival at the open end of the pipe is reflected with sign reversed. The negative reflection then returns to the exhaust port, is reflected unchanged from the port wall, and commences its second journey towards the open end of the pipe. At each reflection the amplitude of the wave is reduced and further attenuation occurs as it travels along the pipe. Thus, neglecting any bodily motion of the gas in the exhaust pipe, successive reflections of opposite sign will arrive at the exhaust port at intervals of $\frac{2l}{V_p}$ seconds, where l is the effective pipe length and V_p is the velocity of sound in the gas. The indicated curve of pressure obtained from the port will thus be compounded of the fundamental pulse and its reflections, together with the residual wave from previous cycles.

Nature of Fundamental Wave.

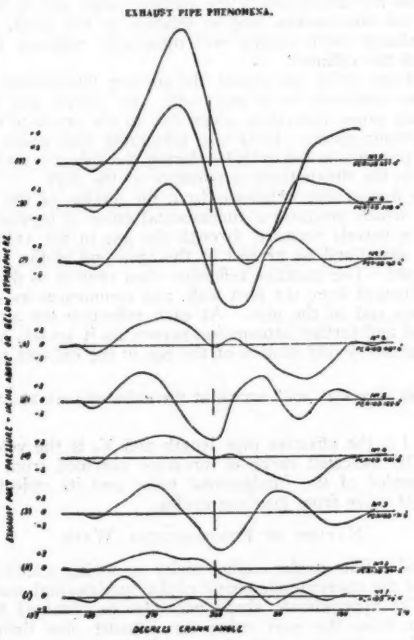
In the case of a four-stroke engine under motoring conditions it is possible to calculate the approximate shape of the fundamental wave of pressure in the port. The approximate shape may also be obtained from indicator diagrams taken from the port using an exhaust pipe drilled in such a fashion as to damp out the residual wave from previous cycles. For this purpose the length of the pipe must be sufficient to ensure that the fundamental is complete before the first reflection arrives back at the measuring point and the degree of damping must be no more than the minimum required to damp out the residual wave.

Figure 3 shows sample indicator diagrams recorded from the four-stroke unit under motoring conditions, using drilled exhaust pipes. In addition to the approximate shape of the fundamental wave, the shape of the first reflection is also discernible in the diagrams for the 2⅞-inch bore pipes. Under the conditions dealt with it was found that the amplitude of the fundamental varied directly as the engine speed and inversely as the sectional area of the exhaust pipe.

During the trials referred to diagrams were recorded with varying amounts of damping, the effect being obtained by drilling rings of holes at intervals along the exhaust pipe. In some cases the exhaust pipe was surrounded by a second pipe, giving an effect similar to that of the Burgess silencer.

In general it appears that the result of interposing a volume part way along the exhaust pipe is to give a change of phase in the net vibration at

the port, the effect being thus to increase the equivalent length of the system by an amount depending on the characteristics of the volume interposed.



No.	Pipe Bore in.	Speed r.p.m.	Nominal Length in.	No.	Pipe Bore in.	Speed r.p.m.	Nominal Length in.
1	2½	1,265	36	6	2½	1,992	114
2	2½	1,265	180	7	1½	1,265	60
3	2½	1,615	60	8	1½	1,615	60
4	2½	1,615	138	9	1½	1,992	60
5	2½	1,992	36				

FIGURE 3.—SINGLE-CYLINDER FOUR-STROKE UNIT. TYPICAL INDICATOR DIAGRAMS. DAMPED TYPE.

In the arrangement commonly used, where the cylinder exhausts directly into a chamber of volume V_1 followed by a tail pipe of length l and area A the system may be shown to be dynamically equivalent to a plain pipe of area A and length $\left(\frac{le}{2}\right)$ where:

$$\tan\left(\frac{\pi l}{le}\right) = \frac{Ale}{\pi V_1} \qquad \text{.....(1)}$$

Where such a system has been adjusted to give favorable conditions in the exhaust port it may still be necessary to use an additional length of pipe to convey the gases to atmosphere. In such a case the approximate characteristics of the primary system may be preserved by placing a second volume V_2 at the end of the primary pipe, the gases there being led from V_2 to atmosphere through a secondary tail pipe. The length of plain exhaust pipe equivalent to the system obtained by placing a volume V_2 only at the end of the primary system is $\frac{L_E}{2}$, where L_E is given by the expression:

$$\tan \frac{\pi l}{L_E} = \frac{\left(\frac{A}{V_1}\right) + \left(\frac{A}{V_2}\right)\frac{L_E}{\pi}}{1 - \frac{A^2}{V_1 V_2} - \frac{L_E^2}{\pi^2}} \qquad (2)$$

If the volume V_2 is chosen so that the characteristics of the resulting system are approximately those of the original primary system, then the addition of a further length of pipe leading from V_2 to atmosphere will not affect matters.

The effectiveness of the second chamber in preserving the characteristics of the original primary system may be shown to depend, not on the actual volume V_2, but on the ratio $\frac{V_2}{Al}$ Thus for the effect of the second chamber and its tail pipe to be small the dimensions of the chamber required will increase with increase in the length of primary pipe in use.

The information at present available as to the effect of different forms of expansion chamber is, however, meager, and further experimental work on the subject is in progress.

Theoretical Curves of Net Exhaust Port Pressure.

Once the shape of the fundamental wave is known it becomes possible to plot the net curve of exhaust port pressure to be expected under given conditions.

Figure 4 illustrates the method. To obtain the net curve it is necessary to plot to a crank angle base the fundamental wave and then, at intervals corresponding to $\frac{2l}{V_p}$ seconds, the successive double reflections of the fundamental.

The first double reflection is made up as follows: The first reflection arrives at the port after an interval of $\frac{2L}{V_p}$ seconds, having traversed twice the length of the pipe and suffered reflection with change of sign from the open end. It thus arrives with an amplitude of $K_o e^{-2Kl}$ times that of the fundamental, where K_o is the reflective coefficient for the open end and K the attenuation coefficient. Immediately on arrival, reflection again occurs, this time from the rear wall of the port with no change of sign, and since only an infinitesimal interval will separate the record of the arrival of the disturbance from the open end of the pipe from the record of

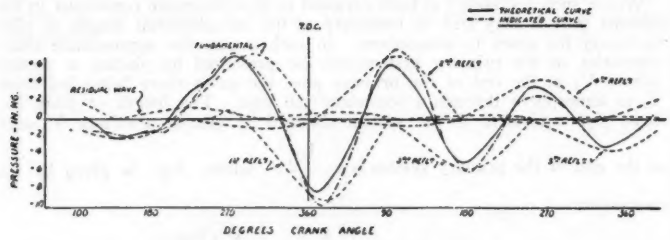


FIGURE 4.—SINGLE-CYLINDER FOUR-STROKE UNIT. EXHAUST PORT PRESSURE CURVE. 2 3/32-INCH BORE PIPE. 1650 R.P.M. NOMINAL LENGTH 54 INCHES.

its passing in the opposite direction after reflection from the port wall, an indicator should record a double negative reflection of amplitude $K_e e^{-2k\lambda} + K_e \times K_e e^{-2k\lambda}$, or $K_e(1 + C_e)e^{-2k\lambda}$ times that of the fundamental, where K_e is the reflection coefficient for the closed end of the pipe.

An interval of $\frac{2L}{V_s}$ seconds then follows whilst the reflection from the rear port wall travels to the open end, is reflected, and returns to the port to be again reflected from the port wall. The indicator then registers a second double reflection of amplitude $e^{-4k\lambda}K_oK_e$ times that of the previous double reflection.

The effect of the attenuation of coefficient K, for pipe lengths normally used, is very small compared to that of the reflection coefficients K_o and K_e. The values of the latter, in the morning trials referred to, were $K_o = 0.84$ and $K_e = 0.96$. It was found, however, that, for satisfactory reproduction of indicator diagrams, it was necessary to multiply the calculated amplitude of the first double reflection, by a further coefficient "x," the value of which was found to be independent of engine speed and pipe length and, for the particular conditions quoted, to conform to the relation

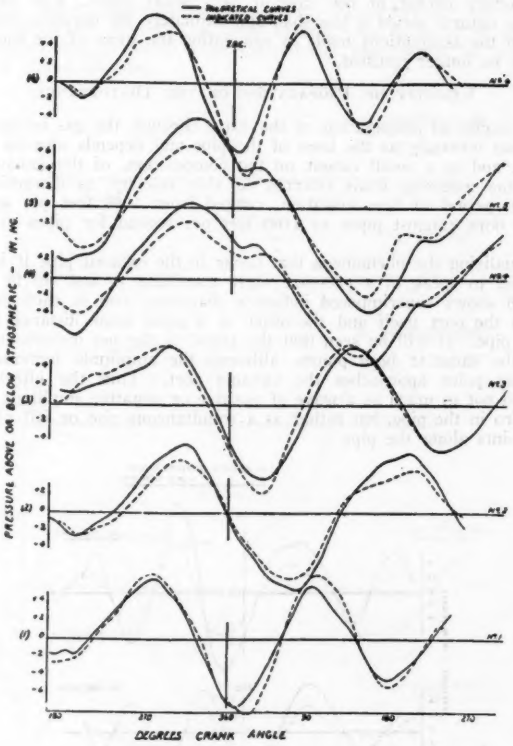
$$x = 0.99 - \frac{0.96}{D^2}, \text{ where D is the pipe}$$

diameter in inches.

Again, as succeeding reflections are plotted, a point is reached where the reflections return to form the residual wave. If the m^{th} double reflection is the first in the residual wave to affect that part of the net curve containing the fundamental, its amplitude will be $x \times K_oK_e e^{-2k\lambda}$ times its predecessor.

The reasons why this additional damping suffers by the first double reflection in each primary and residual wave, as shown by the need for the coefficient x, are not clear. Whilst the affected reflections are travelling in the pipe, however, the exhaust valve is open and gas is leaving the open end of the pipe. It is suggested that, under these conditions the loss of energy to the outside air is increased and the value of K_o reduced accordingly.

Figure 5 shows a series of indicated curves taken from the exhaust port of the single-cylinder four-stroke unit under motoring conditions, together with the corresponding curves obtained by the method described.



No.	Speed r.p.m.	Nominal-Length in.	Natural Period deg.
1	1,265	72	169·4
2	1,265	108	253·0
3	1,615	68	204·5
4	1,615	132	394·0
5	1,992	108	398·4
6	1,992	36	134·2

FIGURE 5.—SINGLE-CYLINDER FOUR-STROKE UNIT. EXHAUST PORT PRESSURE CURVE.

In general the agreement between the indicated and the theoretical curves is satisfactory except in the case of very short pipes. For such pipes, where the natural period is less than approximately 100 degrees crank angle, certain of the assumptions made in calculating the form of the fundamental wave are no longer justified.

Velocity of Propagation of the Disturbance.

The velocity of propagation of the wave through the gas in the exhaust pipe varies inversely as the bore of the pipe and depends also on the temperature, and to a small extent on the composition, of the exhaust gases. During the motoring trials referred to, this velocity, as determined from the mean period of free vibration, ranged from 1060 feet per second for 1⅜-inch bore exhaust pipes to 1100 feet per second for pipes of 2⅞-inch bore.

In visualizing the phenomena that occur in the exhaust pipe it is perhaps misleading to speak of a pressure wave travelling to and fro in the pipe. Figure 6 shows superimposed indicator diagrams, one in each case being taken at the port itself and the other at a point some distance along the exhaust pipe. It will be seen that the phase of the net disturbance is very nearly the same at both points, although the amplitude increases as the measuring point approaches the exhaust port. Thus the effect may be visualized not so much as a wave of positive or negative amplitude traveling to and fro in the pipe, but rather as a simultaneous rise or fall of pressure at all points along the pipe.

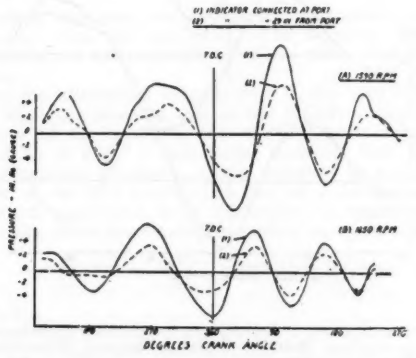


Figure 6.—Exhaust Port Pressure. Single Cylinder. Pipe Length 45.3 Inches.

Exhaust Port Pressure Under Normal Running Conditions.

In a four-stroke engine, when firing normally, there are two fundamental pulses to be considered. The first is produced by the rush of gas when the exhaust valve opens, and the second by the piston motion on the exhaust stroke, the net curve of pressure in the exhaust port being built up of these two fundamentals, together with their reflections.

Figure 7 illustrates the process. The curves "A" are indicator diagrams from the exhaust port of the four-stroke unit under motoring conditions.

For curve (1) the induction pressure was atmospheric, so that only the fundamental due to piston motion is present. For curve (2) the intake air was supplied under pressure, so that in this case there is in addition a second fundamental produced when the exhaust valve opens, as can be seen on the left of the diagram.

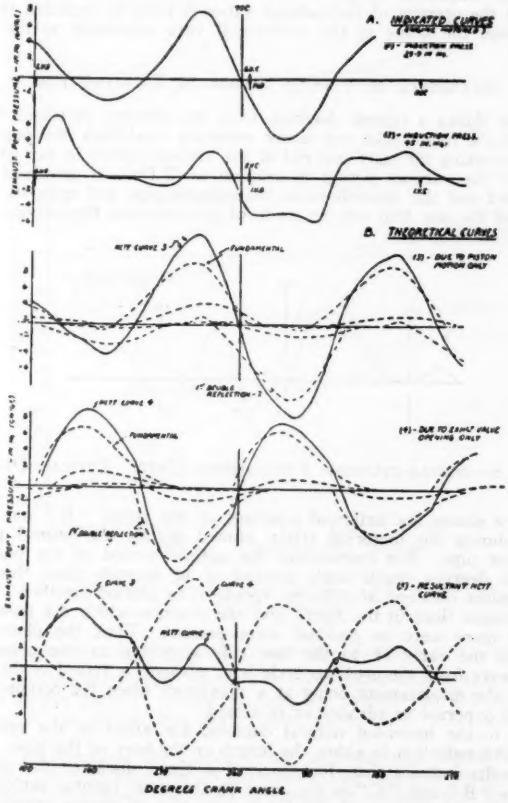


FIGURE 7.—FOUR-STROKE SINGLE-CYLINDER UNIT. EXHAUST PORT PRESSURE. PIPE LENGTH 84.5 INCHES. PIPE DIAMETER 2 3/16 INCHES. SPEED 1590 R.P.M.

Curve (3) is the theoretical curve corresponding to (1), obtained by plotting the calculated piston fundamental together with its reflections.

Curve (4) is obtained by plotting the estimated fundamenal pulse due to the opening of the exhaust valve with its reflections.

Curve (5) shows the theoretical net curve of exhaust port pressure obtained by compounding curves (3) and (4) and is to be compared with the corresponding indicated curve (2). Although the agreement is not perfect, the curves are sufficiently alike to support the explanation given for the shape of curve (2).

Since the amplitude of curve (4) will vary with the pressure in the cylinder at the opening of the exhaust valve, it is to be expected that, in a petrol engine, the shape of the curve will vary according to the throttle opening.

Occurrence of Vacuum Period in Exhaust Port.

Figure 8 shows a typical diagram from the exhaust port and from the cylinder of the four-stroke unit under motoring conditions, the points "B" and "C" marking the start and end of the vacuum period in the port. The position of the vacuum period in relation to T.D.C. is governed by the engine speed and the dimensions of the exhaust pipe and upon its position will depend the use that can be made of the pressure fluctuations for the purpose of scavenging.

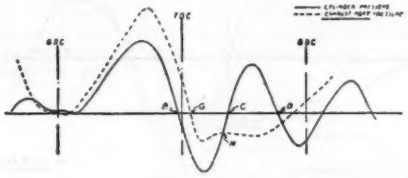


Figure 8.—Single-cylinder Four-stroke Unit. Typical Diagram.

Figure 9 shows the indicated positions of the points "B" and "C," as observed during the motoring trials, plotted against the natural period of the exhaust pipe. For convenience the natural period of the pipe is expressed in degrees crank angle instead of in seconds since this method enables results obtained at different speeds to be plotted together.

The straight lines in the figure give the position which the points would occupy if there were no residual wave present. Thus the plotted points diverge to the early or to the late side according as the phase of the residual wave from the previous cycle is in advance or retard of the primary vibration, the displacement being at a maximum when the residual is one-quarter of a period in advance or in retard.

Owing to the increased natural damping the effect of the residual decreases with reduction in either the length or the bore of the pipe.

The results indicate that, for pipes of a given diameter the position of the points "B" and "C" is the same at the same natural period of pipe (expressed in degrees crank angle) irrespective of engine speed. As the natural period is increased, the vacuum period occurs later in the cycle and the duration of the period increases. The period also occurs later, for pipes of the same natural period, as the bore of the pipe is reduced.

Other things being equal, the maximum depression in the port increases in direct proportion as the engine speed is increased or the pipe bore is reduced. For pipes of a given diameter the amplitude of the vacuum loop reaches an approximately constant value, apart from the effects of the residual wave, if the natural period exceeds some 120 degrees crank angle.

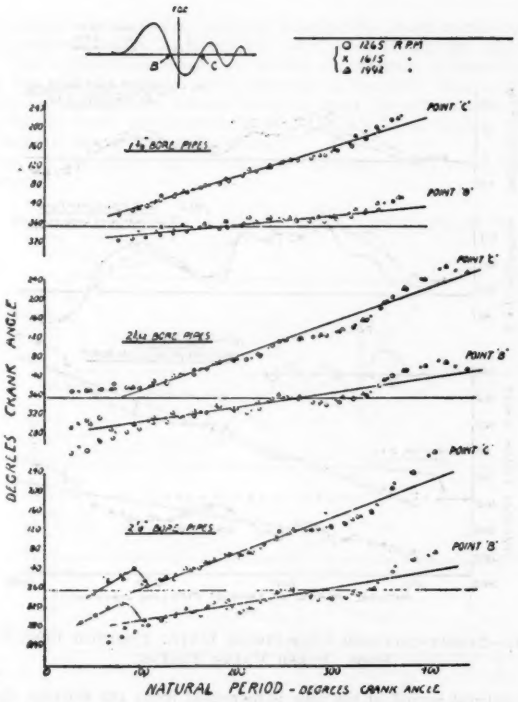


FIGURE 9.—SINGLE-CYLINDER FOUR-STROKE UNIT. EXHAUST PORT VACUUM PERIOD.

PIPE LENGTH FOR MAXIMUM SCAVENGE (FIXED VALVE TIMING).

For maximum scavenging effect, with fixed valve timing and no overlap, the pipe length must be chosen so that the pressure in the port is at a minimum at the instant that the exhaust valve closes and the inlet valve opens.

Figure 10 illustrates the choice of the optimum pipe length under such conditions, the data referring to the four-stroke unit previously mentioned.

Figure 10 (A) shows the effect of change in exhaust pipe length on the indicated pressure in the port at effective E.V.C., which in this case was as at 14 degrees crank angle. Figure 10 (B) shows the corresponding changes in the observed air consumption, expressed as a percentage of that obtained with open exhaust. Figure 10 (C) shows the crank angle at the start and end of the vacuum period in the exhaust port.

At natural periods of 105, 250, and 350 degrees crank angle effective E.V.C. occurs near the start or the end of the vacuum period, when the pressure in the port is approximately atmospheric and Figure 10 (B) shows the air consumption to remain almost unaltered.

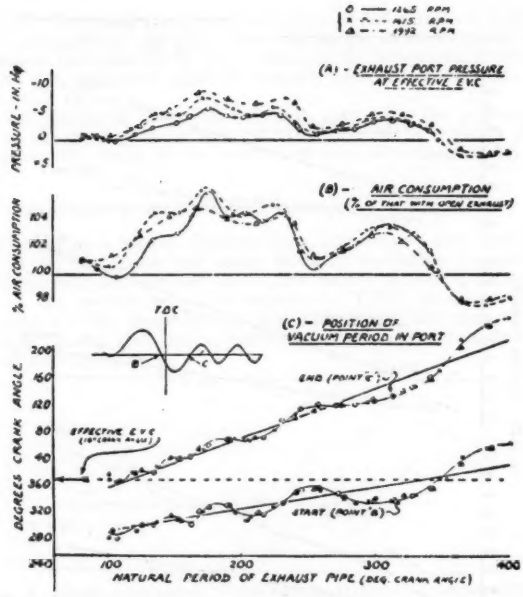

(A) - EXHAUST PORT PRESSURE AT EFFECTIVE E.V.C
PRESSURE - IN Hg
(B) - AIR CONSUMPTION
% AIR CONSUMPTION
(C) - POSITION OF VACUUM PERIOD IN PORT
T.D.C.
END (POINT 'C')
EFFECTIVE E.V.C.
START (POINT 'B')
DEGREES CRANK ANGLE
NATURAL PERIOD OF EXHAUST PIPE (DEG. CRANK ANGLE)

FIGURE 10.—SINGLE-CYLINDER FOUR-STROKE UNIT. 2⅞-INCH BORE EXHAUST PIPE. FIXED VALVE TIMING.

As the natural period of the pipe is increased from 105 degrees, the center of the vacuum loop approaches the point of effective E.V.C. and the consumption rises until a period of 115 degrees is reached. At this point effective E.V.C. occurs at the center of the vacuum loop and maximum consumption is attained. With further increases in the natural period the center of the loop moves away from the E.V.C. and the consumption falls until a period of 260 degrees is reached.

For pipes of natural period greater than 360 degrees, effective E.V.C. occurs before the start of the vacuum period, when the pressure is above atmospheric, and the consumption falls below that obtained with open exhaust.

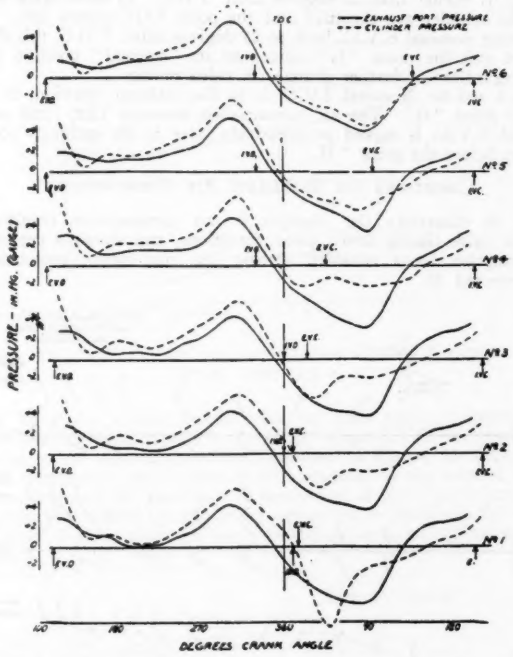
The pulsations which occur in the induction pipe of an internal combustion engine are subject to the same general laws as those governing the fluctuations in the exhaust pipe. By arranging conditions so that the pressure in the inlet port is a maximum at effective I.V.C. the pulsations in the inlet pipe may be made use of to secure a supercharging effect.

VALVE TIMING FOR MAXIMUM SCAVENGE (FIXED PIPE LENGTH).

Mention has been made of the fact that, for the unit used, a difference of some 16 degrees separated the nominal and effective positions of inlet valve opening and exhaust valve closure. Experiments showed, however, that,

for maximum scavenge, the optimum position for these events was actually some 25 degrees before the point "G" and some 25 degrees after the point "H." The explanation appears to be that the increase in breathing capacity due to the slightly greater valve opening in the early stages of suction is sufficient to outweigh the effects resulting from the pressure in the cylinder being slightly above atmospheric at effective I.V.O., a similar reason holding in regard to exhaust valve closure.

Figure 11 illustrates the selection of optimum valve timing for a fixed pipe length:



No.	Nominal				Rel. Air Taken
	I.V.O.	I.V.C.	E.V.O.	E.V.C.	
1	15	205	115	10	Unity
2	0	213	115	10	1·024
3	0	213	117	25	1·042
4	331	205	109	45	1·122
5	332	206	109	97	1·256
6	332	206	109	140	1·279

FIGURE 11.—SINGLE-CYLINDER FOUR-STROKE UNIT. PIPE DIAMETER 2 3/32-INCHES. LENGTH 120 INCHES. 1265 R.P.M.

In No. 1 (relative air consumption unity) the over-early E.V.C. causes throttling towards the end of the exhaust stroke and the point "G," where the cylinder pressure returns to atmospheric, is late. I.V.O. is also late and the cylinder pressure falls considerably during the early part of suction.

In No. 2 (consumption 1.024), the effect of the increased breathing capacity due to the earlier I.V.O. is that the point "H" does not occur until 120 degrees crank angle, so that a very much later timing for E.V.C. could be used with advantage.

No. 3 (consumption 1.042) shows an effect which occurs whenever nominal E.V.C. is earlier than 25 degrees after T.D.C. In such cases the gases leaving the cylinder are throttled and the point "G" occurs late.

By moving nominal E.V.C. back to 25 degrees after T.D.C. this throttling is avoided and the point "G" moves to its "normal" position where it remains regardless of further changes in valve timing.

Nos. 4, 5 and 6. Nominal I.V.O. is in the optimum position, 25 degrees before the point "G." The air consumption becomes 1.22, 1.256 and 1.279 as nominal E.V.C. is moved progressively later to its optimum position at 25 degrees before the point "H."

Conditions for Maximum Air Consumption.

Figure 12 illustrates the changes in air consumption resulting from changes of valve timing under given conditions, and shows a typical set of air consumption loops recorded during the four-stroke motoring trials already referred to.

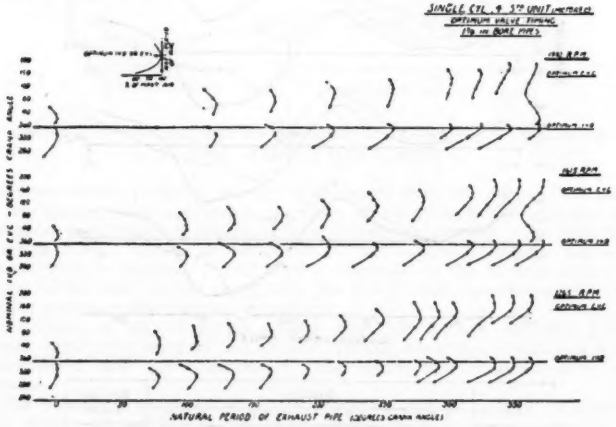


Figure 12.—Single-cylinder Four-stroke Unit. Optimum Valve Timing. 1⅜-inch Bore Pipe.

For each length of pipe there are two loops, one for inlet valve timing and one for exhaust valve timing, the natural period of the pipe being shown on the bottom scale opposite the point of inflection of the loops. In obtaining each pair of loops the exhaust valve was first set to close in approximately the optimum position and the air consumption was measured

for a number of different settings for inlet valve opening. The inlet valve was then set to open in the optimum position and similar measurements were made for a range of settings for exhaust valve closure. The air consumption is expressed as a percentage of the maximum obtained during the particular loop and the optimum positions for nominal I.V.O. and for nominal E.V.C. are shown on the left-hand scale opposite the point of inflection of the appropriate loop.

Figure 13 summarizes the information obtained from the air consumption loops for pipes of natural period up to 360 degrees.

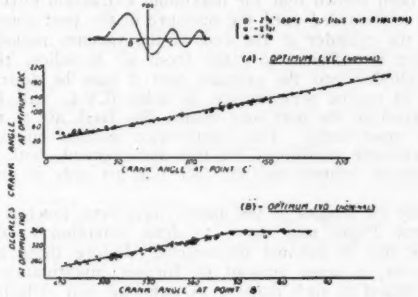
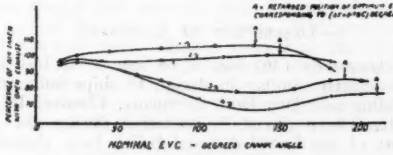

(A) - OPTIMUM E.V.C. (NOMINAL)
CRANK ANGLE AT OPTIMUM E.V.C.
CRANK ANGLE AT POINT C
(B) - OPTIMUM I.V.O. (NOMINAL)
DEGREES CRANK AT OPTIMUM I.V.O.
CRANK ANGLE AT POINT B

FIGURE 13.—SINGLE-CYLINDER FOUR-STROKE UNIT. 2⅞-INCH BORE PIPE. 1992 R.P.M.

Figure 14 shows typical results obtained with pipes of natural period exceeding 360 degrees. It will be seen that when E.V.C. is retarded so as to conform to the optimum position indicated in Figure 13 (A), there is actually a decrease in the weight of air consumed as the natural period of the pipe approaches 360 degrees. If the period of the pipe is greater than 360 degrees the highest consumption occurs with nominal E.V.C. at 25 degrees after T.D.C., although the retarded position still gives a point of maximum.



No.	Nominal Length in.	Natural Period deg.
1	90	320·6
2	96	342·4
3	108	385·0
4	114	407·6

FIGURE 14.—VALVE TIMING FOR MAXIMUM SCAVENGE.

For each size of pipe there is a considerable range of pipe lengths over which a material increase in air consumption is to be obtained by the selection of a suitable valve timing. It should also be remembered that, should an unsuitable timing be chosen, a correspondingly adverse effect on air consumption may result.

In discussing the possibilities of the uses of exhaust pipe effects for scavenging purposes no account has so far been taken of the effects produced on engine performance. In certain of the illustrations given the extreme conditions necessary for the attainment of maximum scavenge are not such as would be desirable or even practicable in normal operation. Again, it has been shown that for maximum extraction effect, the effective E.V.C. should be retarded until the pressure in the port commences to rise above that in the cylinder at the end of the vacuum period. Where the extraction effect is sufficient to cause fresh air to follow the spent gases through the cylinder into the exhaust port it may be desirable, from the point of view of engine performance, to delay E.V.C. still further so that the rising pressure in the port may return this fresh air to the cylinder in the form of a supercharge. The compression ignition engine should offer particularly favorable conditions for this arrangement, both on account of the small clearance volume and the fact that air only is drawn in during induction.

Although only the fringes of the matter have been touched on it is hoped that the present Paper may serve to draw attention to the possibilities offered by the use of exhaust phenomena. Before these possibilities are realized, however, a large amount of further investigation is necessary, especially in regard to such matters as damping and reflection coefficients, effect of silencers, etc., under different conditions of operation both in single and multicylinder engines.

STRUCTURAL FAILURE OF THE TANKER S.S. *SCHENECTADY*.

The American Bureau of Shipping released on March 16, 1943, the following report of the findings of the special Sub-committee appointed to investigate the structural failure of the *Schenectady*. Messrs. A. G. Bissell, E. D. Debes, L. M. Grover, A. A. Norton, H. W. Pierce, and S. H. Graf composed the Committee. The final meeting of the Committee was held March 11, 1943.

I—Description of Casualty.

1. The S.S. *Schenectady* (503 feet × 68 feet × 39 feet 3 inches) is an all-welded tanker exactly similar in design to ships built and building by the Sun Shipbuilding and Dry Dock Company, Chester, Pa., of which no fewer than 23 have been placed in operation during the past year and which, to the best of our knowledge and belief, have shown no structural defects in service.

2. The *Schenectady* was the first tanker built at the new shipyard of the Kaiser Company at Swan Island, Portland, Oregon; had been launched October 24, 1942, and had satisfactorily completed her sea trials. She was lying afloat at the fitting-out dock of the Swan Island Yard when, on Saturday evening, January 16th, 1943, she broke in two with a loud report, fracturing suddenly across the deck at a point just abaft the after end of the bridge about amidships, the fracture extending down both sides to the bottom shell plating which remained intact. All deck, side and bottom

longitudinal frames fractured as did also the plating of the corrugated longitudinal bulkheads and the centerline deck and bottom girders thus constituting a complete structural failure except for the flat portion of the bottom shell plating. In no case did the fractures occur in the transverse welds.

3. The vessel jack-knifed so that the bottom shell plating knuckled transversely and showed above water while the ends of the forward and after sections settled in the silt so that there was a gap of about 10 feet at the deck. There was no leakage of water into the two parts of the tank opened by the fracture and from the character of the fracture the tearing of the side shell appeared to have been more gradual and progressive than the sudden fracturing of the deck from gunwale to gunwale.

4. The forepeak tank, the forward deep tanks, and the afterpeak tank were full of water as ballasted for the trial trip and there was in addition about 3100 barrels of fuel oil in the cross bunkers immediately forward of the machinery space. The resultant bending moment in hogging in still water was about one-half of the maximum design bending moment.

5. The hourly temperature for Saturday, January 16th, 1943, reported by the U. S. Weather Bureau for Portland, Oregon, shows a high of 38 degrees Fahrenheit at 2:30 P. M., in the afternoon, and 23 degrees Fahrenheit at 11:00 P. M. at the time of the failure. The river water temperature was about 40 degrees Fahrenheit. This drop in air temperature of 15 degrees Fahrenheit over a period of 8½ hours, while not extreme as to suddenness, did introduce a factor in respect of the increased brittleness of steel at temperatures below freezing.

6. It was alleged that during the launching of the vessel trouble was experienced with the after launching poppet which resulted in slight damage to the rudder and its pintle, but there was no evidence that such trouble contributed to the failure.

7. It was alleged that during the trial trip one of the anchor chain cables broke as the anchors were dropped to check the vessel's headway, resulting in a definite shock, but this could not have been great enough in magnitude to be of any consequence.

8. It was alleged that the action of the Willamette River had washed a bank of silt under the midship portion of the vessel and that a subsequent drop of river level had in effect caused a stranding. While there was a recorded drop of about 15 inches in water level for the 3½-hour period immediately preceding the failure, there was no evidence of such a silt formation. Subsequent examination of the vessel in dry dock, by the Committee, disclosed no indication of grounding damage.

9. It was also alleged that several people felt a slight seismic disturbance (an earth tremor) at the time of the failure. This was further colored by the fact that the water level indicator located at the yard showed a vertical oscillation of approximately 12 inches at the moment of failure and it is claimed that extreme oscillations of these level indicators always accompany earthquake disturbances. After a thorough investigation it was concluded that the alleged shock had little bearing on the cause of this failure.

II—Factors Contributing to Failure.

After a thorough study of all factors surrounding the failure, including structural design, methods of construction and a complete physical, chemical and microscopic exploration of the material and the welding in way of the fracture, the Committee found the following factors relevant and contributory to the failure.

(*a*) There was a tendency on the part of the shipyard personnel to depart from recognized fundamentals of good welded construction for the laudable

purpose of speeding up construction to the utmost possible extent to meet the needs of the present emergency.

(*b*) There were insufficient numbers of trained experienced welders and ship fitters available for the job at the rate of production maintained and an inadequate number of skilled welding supervisors with the necessary knowledge of the basic elements of good welding practice to exercise proper control over the welders.

(*c*) There was neglect on the part of the personnel to realize the importance of adhering rigidly to established welding procedures and welding sequences necessary to reduce shrinkage stresses to a safe minimum.

(*d*) There was evidence in the sister vessels under construction of poor fitting of large subassemblies which necessitated considerable forcing into position by the excessive use of jacks, turnbuckles, etc. In other cases open joints required the use of an excessive amount of welding to finish the joint resulting in excessive shrinkage.

(*e*) There was a lack of uniformity in the quality of the steel used in the hull structure. For example, as compared with other plates investigated, the particular sheer strake plate on the starboard side where the fracture apparently started had a very low proportional limit (10,000 pounds per square inch) as determined by extensometer readings (stress strain curve); also the Charpy Test impact values for this plate were low, even at room temperatures, and brittle at 20 degrees Fahrenheit; the values from the Notch Bend Tests also showed considerable brittleness. It should be recognized that the Charpy and Notch Bend Tests are not included in the ordinary commercial Tests by which the quality of structural steel is determined.

(*f*) A serious accumulation of shrinkage stresses occurred in the automatic machine welding of the deck assembly joints especially in the longitudinal joint at the gunwale attaching the sheer strake to the stringer plate. This particular welded joint was also found defective in way of the location where the failure started as evidenced not only by a longitudinal crack, but also by what appeared to be minute transverse cracks in the weld.

(*g*) The hogging moment resulting from the distribution of ballast, fuel, etc., in the end tanks produced a tensile stress on the upper flange of the hull girder of approximately 4½ tons p.s.i., which is comparatively moderate and certainly not sufficient in itself to cause any failure in the hull structure.

(*h*) While there is no question with regard to the sufficiency of the vessel's structure, there being no departure from recognized and proven design standards, the abrupt termination of the bridge-end fashion plates at the top of the sheer strake did constitute a serious point of stress concentration especially in a welded structure.

III—Summary.

In the opinion of the Committee the failure of the hull structure of the tanker *Schenectady* was due to a combination of unfavorable circumstances. The principal cause was an accumulation of an abnormal amount of internal stress locked into the structure by the processes used in construction together with an acute concentration of stress caused by defective welding at the starboard gunwale in way of the abrupt ending of the bridge fashion plate, augmented by the hogging stress due to the ballasted condition; this accumulation and concentration of stress caused a tensile failure at the starboard sheer strake which was formed of steel of sub-standard quality, all of which was aggravated to some degree by the drop in atmospheric temperature.

IV—Conclusion.

The procedure immediately recommended and carried out whereby the defective welding previously referred to was removed from the S.S. *Schenectady* and sister vessels and these joints properly rewelded has proven a satisfactory corrective measure as demonstrated by the application of severe bending tests (hogging and sagging). It is the opinion of the Committee that the high stresses responsible for the fractures that have recently occurred in welded vessels were due primarily to the failure to adhere rigidly to the procedure necessary to keep shrinkage stresses within the margin of strength allowed in the design. Steps have been taken with the full cooperation of all yards concerned to insure adherence to proper established procedure and the managements of the yards are fully alive to their responsibilities in the matter. The Committee feels that closer control of welding procedure in which the builders have already been instructed will prevent a recurrence of such major failures. It is also the opinion of the Committee that the probability of fractures resulting from residual stresses in welded construction will decrease with the length of service.

BLACKOUT LIGHTING.

Mr. L. C. Porter reports the progress of extensive investigations made to determine permissible lighting levels during blackouts, and resulting equipment, technique and specifications now available for use. Mr. Porter is the Co-ordinator of Blackout Activity of the General Electric Company. His article is reprinted from General Electric Review, December, 1942.

For a great many years illuminating engineers have been concentrating on the development of bigger and brighter light sources. Today many of us are in the peculiar position of trying to develop ways and means of blacking out the sources which we spent so many years placing in use. Blackouts are steadily increasing in number and they are being extended to different localities, particularly along the eastern and western coasts and the adjacent states. There is, therefore, a great deal of interest in this subject.

Obviously the primary purpose of blackouts is to prevent enemy bombers from locating targets at night. With present navigation instruments and facilities, and such landmarks as rivers, coast lines, railroads, etc., it probably would not be difficult to locate a large city even were it 100 per cent blacked out. On the other hand, blackouts are very effective in confusing an aviator as to the location of vital manufacturing plants, sources of power and water supply, etc., and they make it difficult for the bombardier to hit specific targets. It is to accomplish these things that blackouts are being put into operation in this country. In addition to the dimming or extinguishing of lights, consideration is also being given to the use of smoke for camouflage purposes, and some research is being devoted to glare barrage.

While the purpose of blackouts from our point of view is protection, in that they make it difficult for the enemy to bomb definite targets, on the other hand they benefit the enemy particularly where they have not been carefully organized and skillfully carried out. When a blackout is ordered in areas producing war material it may mean at least a temporary stoppage of production. It often means an increase in accidents, sometimes fatal. The blackout offers increased facilities for sabotage and has a very definite

tendency to lower the morale of our people. For these reasons it is essential that blackouts be worked out with great care and that practice blackouts be held against the time when they will be necessary.

Problems Involved.

One does not fully realize how extensively human activities depend upon light until a study is made of the problems of obscuring it. As a matter of fact, there is almost no human activity which does not depend either directly or indirectly, at one time or another, on artificial light. During blackouts it is desirable to keep a practical amount of light available for use, and at the same time conceal it from observation by enemy bombers or submarines. Some of the major blackout problems are discussed in the following paragraphs.

Manufacturing Plants.

If a manufacturing plant is working on war production there should be only one answer to the problem, the complete obscuration of all externally visible light and the maintenance of full lighting inside so that there will be no interruption to production up to the time when bombing is imminent. This involves not only the blacking out of skylights, windows, elevator shafts, and entrances and exits to the factory, but it also entails complicated ventilation problems under these conditions, as well as various forms of emergency lighting in case enemy bombs open holes in the roofs or walls of the plant.

There are some who advocate opaquing windows, etc., either by paint or by shutters of one kind or another. There are others who advocate continuing operation until enemy bombers are in the immediate vicinity and then pulling the main power switch.

The obscuration of a manufacturing plant is largely a matter of mechanics rather than a lighting problem. Of course, it raises questions as to the relative merits of painting the windows versus the construction of shutters, and the concurrent questions as to kinds of paint to use, methods of application, duration, and costs, as well as composition of shutters, construction of light locks, etc. The War Department is now studying ways and means of dimming regular factory-lighting units to avoid the installation of a separate blackout-lighting system for building interiors, and in this way reduce the cost, labor, and critical materials involved in such installations.

Street Lighting, Traffic Signals, Warning Beacons.

This is the second major problem. Undoubtedly our enemies are well supplied with photographs of our major cities. Naturally street-lighting patterns are of great assistance in leading to critical and congested areas.

Automotive Transportation.

Along with street lighting go the problems of automotive transportation. Automobiles, trucks, buses, trolley cars, passenger cars, all are spectacular beacons when observed from the air. Ways and means of making these vehicles invisible from the air and at the same time allowing at least the essential ones to be driven with some degrees of safety are the requirements of automotive blackout.

Railroad Transportation.

The railroads of the country have a tremendous blackout problem, not only for passenger and freight trains, which involves the lighting of the

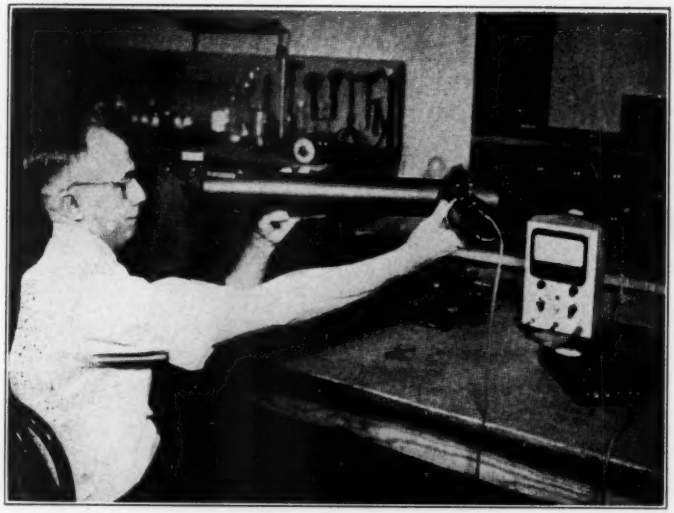


FIGURE 1.—THE LOW-BRIGHTNESS METER, ONE OF THE SPECIAL INSTRUMENTS DEVELOPED FOR USE IN CONNECTION WITH THE BLACKOUT TESTS.

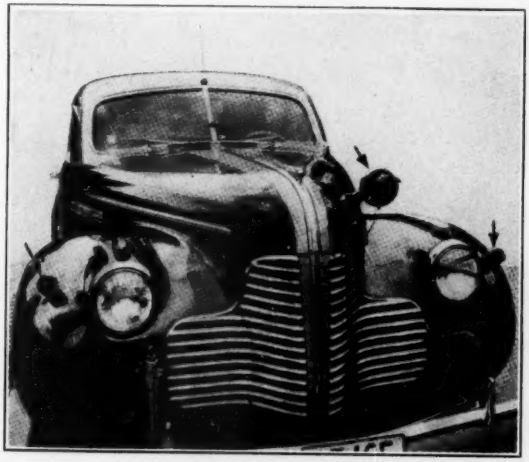


FIGURE 3.—STANDARD MILITARY BLACKOUT HEADLAMP AND MARKER UNITS INSTALLED ON A CAR.

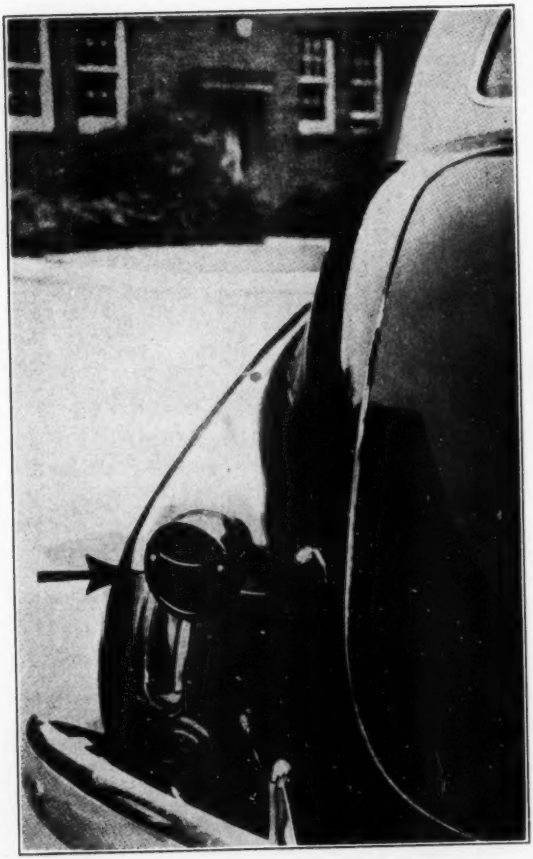


FIGURE 4.—THE STANDARD MILITARY BLACKOUT TAIL AND STOP LIGHT.

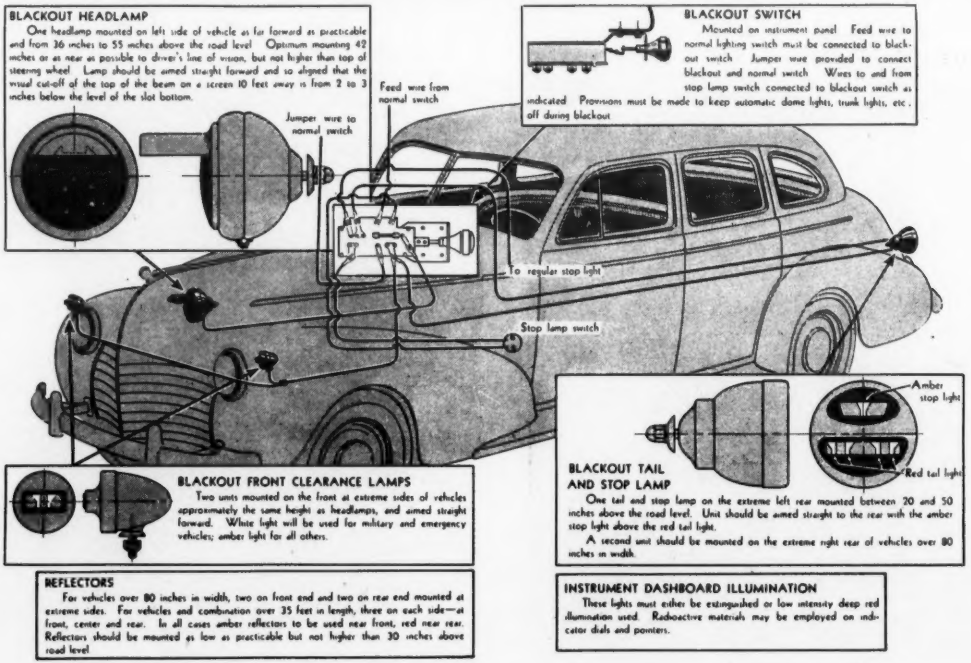

BLACKOUT HEADLAMP
One headlamp mounted on left side of vehicle as far forward as practicable and from 36 inches to 55 inches above the road level Optimum mounting 42 inches or as near as possible to driver's line of vision, but not higher than top of steering wheel Lamp should be aimed straight forward and so aligned that the visual cut-off of the top of the beam on a screen 10 feet away is from 2 to 3 inches below the level of the slot bottom.
Jumper wire to normal switch
Feed wire from normal switch
BLACKOUT SWITCH
Mounted on instrument panel Feed wire to normal lighting switch must be connected to blackout switch Jumper wire provided to connect blackout and normal switch Wires to and from stop lamp switch connected to blackout switch as indicated Provisions must be made to keep automatic dome lights, trunk lights, etc., off during blackout
To regular stop light
Stop lamp switch
Amber stop light
Red tail light
BLACKOUT TAIL AND STOP LAMP
One tail and stop lamp on the extreme left rear mounted between 20 and 50 inches above the road level. Unit should be aimed straight to the rear with the amber stop light above the red tail light.
A second unit should be mounted on the extreme right rear of vehicles over 80 inches in width.
BLACKOUT FRONT CLEARANCE LAMPS
Two units mounted on the front at extreme sides of vehicles approximately the same height as headlamps, and aimed straight forward. White light will be used for military and emergency vehicles; amber light for all others.
REFLECTORS
For vehicles over 80 inches in width, two on front end and two on rear end mounted at extreme sides. For vehicles and combination over 35 feet in length, three on each side—at front, center and rear. In all cases amber reflectors to be used near front, red near rear. Reflectors should be mounted as low as practicable but not higher than 30 inches above road level
INSTRUMENT DASHBOARD ILLUMINATION
These lights must either be extinguished or low intensity deep red illumination used. Radioactive materials may be employed on indicator dials and pointers.

FIGURE 5.—SHOWING THE LOCATION AND WIRING OF THE AUTOMOTIVE BLACKOUT EQUIPMENT.

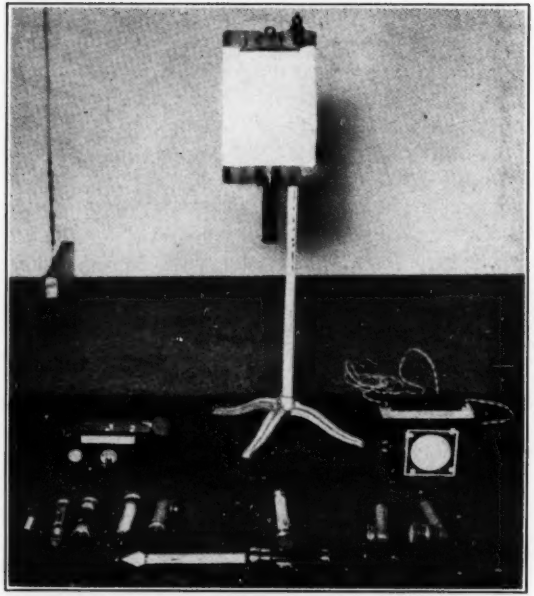


FIGURE 6.—TYPES OF BLACKOUT FLASHLIGHTS AND SPECIAL MEASURING APPARATUS.

FIGURE 7.—THE INDOOR BLACKOUT LAMP. THE BULB IS OPAQUED EXCEPT FOR AN ORANGE-COLORED APERTURE ON THE END OF THE BULB.

Special Measuring Apparatus.

on the End of the Bulb.

Figure 8.—When Approved Indoor Blackout Lamp Is Located Above Tops of the Windows It Is Unnecessary to Draw Window Shades During Blackouts.

Figure 9.—The Use of a Two-way Socket Permits Quick Switching From Normal to Blackout Lighting.

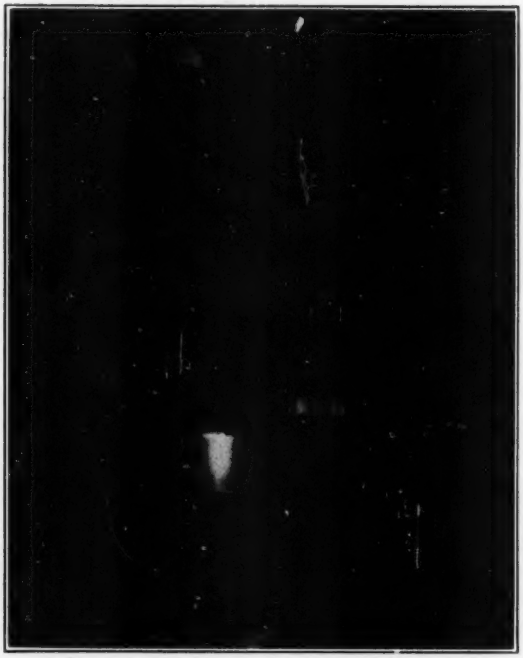


FIGURE 10.—THE INDOOR BLACKOUT LAMP MAY BE USED IN CONVENIENT OUTLETS BY MEANS OF A SHORT CORD, PLUG, AND SOCKET.

FIGURE 11.—A FLASHLIGHT-TYPE TRAFFIC-CONTROL BATON.

FIGURE 12.—A DRY-BATTERY-OPERATED TRAFFIC-CONTROL UNIT. SHOULDER BOXES SHOW RED TO FRONT AND REAR, AND GREEN TO THE SIDES.

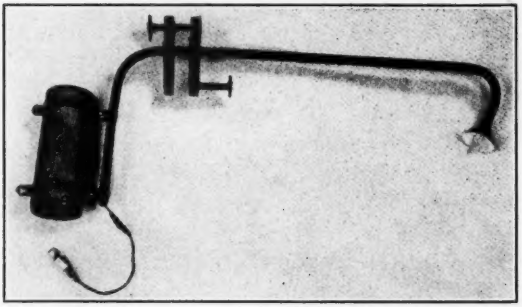


FIGURE 13.—DRY-BATTERY-OPERATED UNIT DESIGNED FOR ATTACHMENT TO DIRECTION SIGNS, ETC. SIGN THUS ILLUMINATED IS VISIBLE FOR SEVERAL HUNDRED FEET BUT INVISIBLE AT BOMBING ALTITUDES. BATTERY WILL OPERATE LAMP CONTINUOUSLY FOR MORE THAN A MONTH.

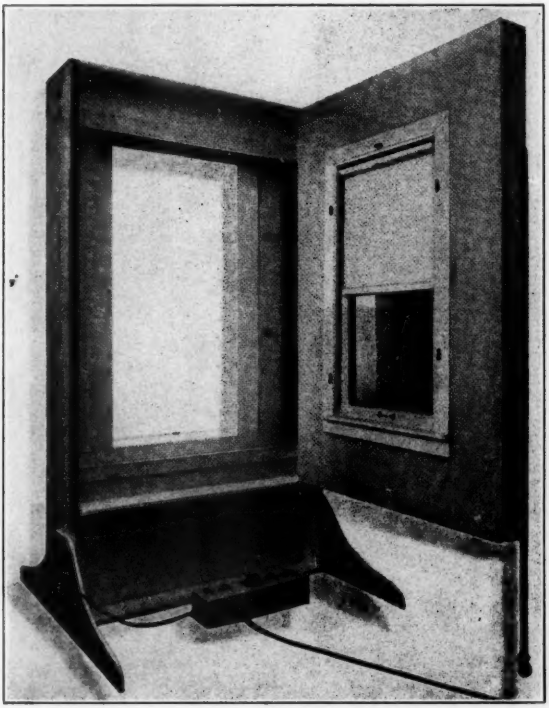


FIGURE 14.—EQUIPMENT FOR STUDYING MATERIALS AND MEANS FOR OBSCURING WINDOWS DURING BLACKOUTS.

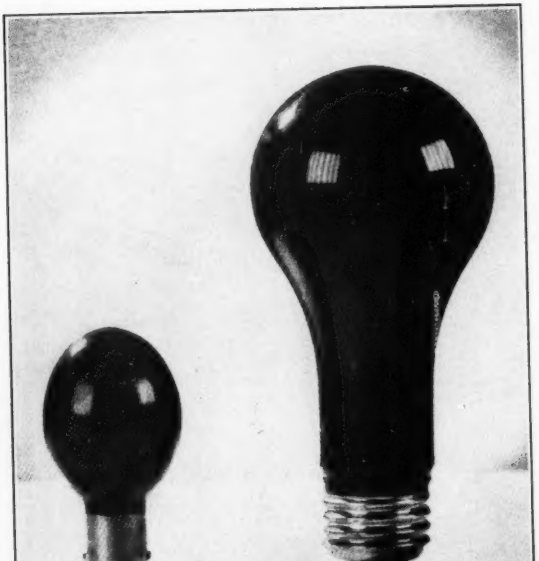


FIGURE 15.—BLACKOUT PHOTOFLASH LAMPS FOR TAKING PHOTOGRAPHS ON INFRARED FILM WITHOUT SHOWING VISIBLE LIGHT.

cars themselves, the use of locomotive headlights, the glare from the fire door when it is opened, rear-end marker lights, the use of fusees, brakemen's hand-lanterns. signals, switching lights, the visibility of locomotive smoke against the background of the sky, but also the problem of their repair shops, signal towers, and floodlighting of classification freight yards, lighting of passenger stations, train sheds, platforms, etc.

Groups of Buildings.

Then there is the problem of blacking out groups of buildings where many people congregate, such as schools, stores, offices, hotels, hospitals, apartments, etc. People have to live and they cannot do it in complete darkness. On the other hand, with enemy bombers overhead, they must carry on such activities as are necessary without revealing their presence by means of lighting.

Advertising Signs.

Another problem is that which involves elimination of the large amounts of light located in relatively small areas, such as the advertising signs in our big cities, theater marquees, such floodlighted areas as ball parks, etc. The signs in particular are a problem along the coast, as much of the sky brightness comes from light emitted directly upward, to which signs are large contributors.

Water Transportation.

Transportation by water as well as on land offers many blackout problems—not only the question of running ships in darkness with consequent danger of collision, but the lighting problems on piers, loading docks, the use of lighthouses, range lights, signalling equipment, and particularly the sky glow silhouette problem. There is also the danger of a ship revealing itself by successively blocking off one light after another as it passes along the shore.

Other Problems.

Then comes the problem which probably directly concerns the greatest number of people, namely that of blackout in the home. Not only in the home, but also at one time or another in most other activities, flashlights are used, and obscuring them from enemy observation is another major problem.

There are also many minor problems, some of which perhaps may not occur to those who have not made a study of the subject. For example, a good many outdoor wattmeters have small lamps which burn continuously. Air raid wardens in blackout areas feel that such lights should be put out. Probably they should be, unless they are shielded from above. Other more or less scattered though perhaps serious problems are indicator lights used on baby chick brooders, hot beds, and various other pieces of farm equipment. Another problem, which perhaps is not frequently thought of, is that of the reflection of antiaircraft searchlights, flares, or even street lights from the shiny tops of automobiles.

Need for Basic Data.

The U. S. Army Engineer Board has for years been making studies of the various problems involved in blackouts. During the past year this work has been greatly accelerated and the army engineers asked for the facilities of the laboratories and the help of the lighting technicians of the General Electric Company, particularly of the Lamp Department.

Since the summer of 1941 intensive studies and a great deal of research, both in the laboratory and outdoors, have been going on under the direction of Major Warren S. Everett, of the Army Engineer Board. Of course, the basis of this work was study and analysis of such information as was already available. For example the minimum candlepower that the human eye could detect under laboratory conditions (called the threshold of vision) was well known; i.e., at 100 feet a pinpoint of light of 0.000001 candlepower; at 1000 feet. 0.0001 candlepower; at 5000 feet, 0.003 candlepower. Just how much this value would have to be modified to meet various outdoor conditions involving such things as the absorption of the atmosphere, distance of observation, brightness, and color of background was not well known. Of considerable help in obtaining this information was the work which has been done by the Lighthouse Department in connection with beacons, range lights, etc., the experience which was gained at the time beacons were developed for the U. S. night air mail.

Nevertheless in addition to all this information, many tests had to be made to determine how many times the laboratory threshold value of illumination we could use for blackout lighting. Investigations to determine this were conducted in different localities and using various methods. For example, street-lighting tests were conducted in which various levels of illumination on streets of different reflection factors, both wet and dry, were observed from planes flying simultaneously at 2000, 5000 and 10,000 feet.*

Studies of this sort are complicated, require a lot of equipment, radio communication between the planes and the sources on the ground, as well as telephone communication along the test course. The test area has to be completely blacked out and the roads closed off and patrolled to prevent unauthorized cars from moving on them. Furthermore. the time that such tests can be made is rather limited, as they must be made in the dark of the moon and in reasonably clear weather. In connection with the particular test mentioned, observations were made not only of the visibility of the streets but also of the visibility of moving army trucks, troops, etc., under different conditions of street lighting.

Early last winter another investigation was conducted to evaluate the visibility of house windows, both with and without shades drawn and with different colors of light. This was done in order to determine how low the interior lighting would have to be to make it suitable during blackouts. Some of these tests were conducted in a small village by a lake, the test house being located on a hill on one side of the lake and the observers in a house on another hill on the opposite side of the lake. The entire telephone system of the village was taken over for the study, lights put out in all of the neighboring houses, and many readings made with instruments in the test house while the observers were outdoors in near-zero weather recording what they could see.

A little later, and still in very cold weather, three summer cottages located on the Great Lakes were used for an accurate study of window-shade brightness. Shades were lighted with red, blue, white, and orange colored light. Brightness measurements were made and simultaneous observations were taken from a dirigible riding at probable bombing altitude. Equipment was used to increase and decrease the brightness of the window shades, and many check tests were reported by radio phone from the dirigible. Observations were also made as to whether a single window or a row of windows could be more readily seen. Further observations were made of the visibility of different types of traffic signals, flashlights, and obstruction lamps.

* I. E. S. Transactions, Vol. 36, No. 10, December, 1941.

On the Atlantic Coast additional observations were made from dirigibles relative to the effect of street lighting, traffic signals, and various types of automotive equipment in aiding the detection of a convoy of army trucks.

At another place in the East all of the buildings in a small town were equipped with indoor blackout lamps. Knowing the approximate location but actually having to see lights to locate it exactly, attempts were then made to locate the town from observation planes.

Still further aerial observations have been made of flashlights. This was done in order to develop a flashlight which could not be seen when pointed directly at observers at bombing altitudes, and to find out how much more light, if any, could be used when the flashlight was directed at a piece of white paper, a map for example, and the paper observed from the air.

The many complicated problems facing the railroads have already been mentioned. Two weeks were spent in the South making aerial observations of all sorts of railroad-lighting equipment. Recently in a large railroad center in New England the shops, passenger station, signal towers, round houses, classification yards, machine shops, etc., were completely equipped with blackout lamps and attempts made to locate them from the air. Check tests were made in several other parts of the country.

Coast Guard boats and dirigibles recently made observations of street lighting reflected from the shiny tops of automobiles, the relative visibility of traffic signals dimmed down to low brightness or partially blocked off by opaque screens, the obscuration of shore lights by moving ships, etc., and the detectability of a string of indoor blackout lamps as they might be used to light a long railroad station platform.

In most of these tests data were taken by means of a special instrument which determines the particular conditions of visibility in terms of the laboratory threshold values. This permits one set of test results to be compared with those made under different conditions and in different locations. All of these data are being correlated and used in the preparation of blackout procedure. In order to make the data recordable and reproduceable, special types of instruments were developed, particularly a low-brightness meter (Figure 1) which will measure brightnesses as low as 0.000005 footlambert.* The sensitivity of the instrument is apparent when we consider that starlight on a moonless night is about 0.0002 footcandle, which on a white surface of 100 per cent reflection factor would give 0.0002 footlambert and with reflection factors of the order of most things in nature would still give brightnesses considerably above the minimum value the instrument will measure.

Results.

These investigations, together with work which had previously been done in some of the European laboratories, showed that there are definite relations between the brightness of a light source, or a secondary source by reflection, and size and visibility at different distances. For example, a person using a flashlight on a piece of paper, such as a map, can use considerably higher brightness than can be used in street lighting on a much greater surface of a light concrete road. Also, a light source of fixed area can vary considerably in its candlepower depending upon the distance from which it is observed. The inter-relations of these factors have been carefully worked out and prepared in the form of a nomograph (Figure 2).†

* I. E. S. Transactions, Vol. 37, No. 1, January, 1942.

† This nomograph is based on reports of seven outstanding investigators, which have been compiled in a paper entitled "Illumination and Blackouts," by P. J. Bouma, Philips Technical Review, Vol. 4, No. 1, p. 15, January, 1939. Larger copies of this nomograph are available as General Electric print LS-142.

Color is one of the most complicating factors entering into the blackout studies, particularly when it involves seeing at very low brightnesses. For a long time it was thought, in fact it is probably still the general belief, that blue is the least detectable light source. Blue was used during the first World War and has probably been generally accepted because of the high light absorption of blue coatings. Coating a lamp or the globe of a light source blue is about the most effective means to greatly reduce its candlepower. Many observations of this type have been made; in fact the Coast Guard has reported that they can see red lights four times as far as they can see blue ones at Atlantic City, and for that reason the city officials are using blue light on the Boardwalk. Using two lamps of the same wattage, one coated red and the other blue, the red light will, of course, be seen farther on account of its higher light transmission properties. At equal candlepower and equal brightness we have a different story. Furthermore, the characteristics of the human eye are such that it sees red when looking directly at it; in other words, the center of the eye is sensitive to red. The side of the eye is very much more sensitive to blue, and blue is visible over a much wider angle. Therefore, when bombing planes are searching for light sources it has been proved that they pick up blue sources more readily than red ones. On the other hand, once red is seen it is more surely an indication of artificial lighting and probably an attempt to protect something.

It is known that the eye focuses more sharply on red than on blue. At very low brightnesses it is easier to read fine print, the dials of instruments, etc., under red light than under blue. Several times the level of illumination of red can be used than of blue without any greater detectability. However, for general seeing, such as trying to move about a room without stumbling over furniture, blue or white (which contains some blue) are better because under blue light we see things out of the side of our eye without necessarily looking directly at them. As a result of tests the War Department issued a directive that blue illumination would be no longer used for blackout purposes.

The use of red lights for blackout purposes in public buildings is liable to cause confusion with red exit and danger signs, which is another reason for not using it for indoor blackout lamps. As against this, the eye becomes dark adapted very much more rapidly under red light than under blue or white light. This was one of the factors resulting in the army's adoption of red.

Problems at army posts, however, are quite different from those in the home. For example, red distorts colors and is psychologically irritating, particularly to women. Under red light, for example, they cannot tell whether they are cooking liver or pork chops, red beets or green peas, from the color standpoint.

Hence, for the indoor blackout lamp a compromise was made on orange. This color is pleasant to work under, results in reasonably normal color rendition, and at the same time it filters out most of the blue, some of which is present in white light.

The same type of reasoning was probably responsible for the first proposals to use red in blackout flashlights. Orange light has been standardized for blackout flashlights.

Accomplishments.

As a result of all of the test work which has been done here and the study of English blackout methods and equipment, which are quite different from those in the United States due to different conditions, the Army

Engineer Board has in preparation or has issued War Department specifications for (1) blackout street lighting, (2) blackout automotive-lighting equipment, (3) blackout railroad-lighting equipment, (4) blackout of buildings, (5) blackout flashlights, (6) luminescent materials, and (7) traffic control during blackouts. Of these, specifications for street lighting, military automotive equipment, blackout of buildings, flashlights, and luminescent materials have been issued.

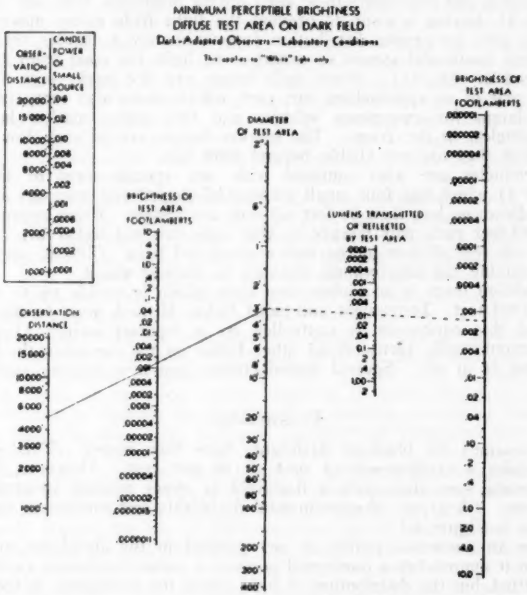

MINIMUM PERCEPTIBLE BRIGHTNESS
DIFFUSE TEST AREA ON DARK FIELD
Dark-Adapted Observers—Laboratory Conditions
OBSERVATION DISTANCE
CANDLE POWER OF SMALL SOURCE
BRIGHTNESS OF TEST AREA FOOTLAMBERTS
DIAMETER OF TEST AREA
LUMENS TRANSMITTED OR REFLECTED BY TEST AREA
BRIGHTNESS OF TEST AREA FOOTLAMBERTS

FIGURE 2.—NOMOGRAPH FOR DETERMINING RELATIONS BETWEEN OBSERVATION DISTANCES, THE SIZE OF ILLUMINATED OR LUMINOUS AREAS, THRESHOLD BRIGHTNESS, AND THRESHOLD LUMENS. THE SCALE IN UPPER LEFT CORNER OF NOMOGRAPH CAN BE USED TO OBTAIN THRESHOLD CANDLEPOWER OF A SMALL SOURCE AT DIFFERENT DISTANCES.

Example: Observation distance 5000 feet; diameter of test area, 3 feet. Threshold brightness of test area will be 0.0014 footlamberts. Lumens transmitted or reflected by test area will be 0.01.

STREET LIGHTING.

The street-lighting specification calls for the use of average intensities of 0.0003 footcandle and not more than 0.0006 footcandle on the street, i.e., approximately twice the intensity of starlight. The light distribution from street lights giving this intensity is also specified and is such that only 1.5 candlepower may be emitted in any direction below the horizontal for

any mounting height, and practically no light above the horizontal. To meet this requirement 9-watt S-14 bulb inside-frosted lamps of 5000 hours' life are specified, and equipment with prismatic control of the light distribution has been developed.

Automotive Lighting.

The automotive-lighting specification requires the equipping of all military vehicles, and any others to be used during blackouts, with one headlamp (Figure 3), having a visor to prevent the light from going upwards, and a lens to give the proper distribution (approximately 8 degrees vertical and 60 degrees horizontal spread so aimed as to light the road from 20 to 150 feet ahead of the car). Since such lamps are not easily seen from the driver's seat of an approaching car, each vehicle must also carry two white marker lamps for emergency vehicles and two amber marker lamps for other vehicles, in the front. The marker lamps are of such low candlepower that they are not visible beyond 1000 feet.

The vehicles are also equipped with one special form of tail light (Figure 4) which has four small trapezoidal-shaped red openings so spaced that at distances less than 60 feet all four are visible. From approximately 60 to 180 feet each pair merges so that only two red lights are seen, and beyond 180 feet all four merge into a single red light. This is very helpful in determining the approximate distance to the car ahead.

In addition there is an amber stop light which is visible up to approximately 1000 feet. Instrument and panel lights, if used, must be deep red.

All of this equipment is controlled by a separate switch (Figure 5) which automatically turns off all other lights on the car when the blackout equipment is in use. Several manufacturers are now making such equipment.

Flashlights.

Specifications for blackout flashlights have been issued. This specification permits a candlepower of 0.04 ± 50 per cent. However, the user should make sure that such a flashlight is never pointed upward during a blackout. (A group of experimental flashlights and measuring equipment is shown in Figure 6.)

Where an automatic switch is incorporated in the flashlight to turn it off when it approaches a horizontal position a somewhat higher candlepower is permitted, but the distribution of light above the horizontal in the lighted position must not exceed the following values:

Angle Above Horizontal	*Maximum Candlepower*
80°	0.04
60°	0.05
40°	0.10
30°	0.15
20°	0.35
15°	0.60

and the total light output is limited to 0.6 lumen, ±50 per cent.

Indoor Blackout Lighting.

The specification for blackout of buildings for the indoor units specifically requires an orange-colored source which emits not less than 1.5 and not more than 3 lumens; not more than 0.15 lumen (5 per cent of the maximum) may be emitted above the horizontal. The maximum candle-

power in any one direction may not be over 1.0. Where an incandescent lamp is used without attachments or auxiliary equipment an A-15 bulb (Figure 7) is specified, this bulb to be opaqued with some material which is not easily scratched off, except for an orange-colored aperture on the end of the bulb of not over one inch in diameter. No more than 15 watts are permitted in such a bulb, and an average laboratory life of 1000 or more hours at rated voltage is specified.

Along with the specification of the light source goes a set of rules for use. For example, the end of the bulb must not be pointed toward a window. Where no shades or other window covering are used the lamps must be mounted above the tops of the windows (Figure 8). Lamps may not be located closer than 10 feet together, the reason for this being that if two or three lamps were grouped together over a white tablecloth in the dining room, as an illustration, the brightness of the cloth would be sufficient to enable its detection. In small or medium size rooms (not over 200 square feet of floor area) one unit per room is specified (Figures 9 and 10); in larger rooms and in corridors, not more than one unit per 100 square feet of floor area.

The use of a special blackout bulb has many advantages over various devices designed to be used with existing lamps and fixtures to reduce their light output to permissible values. First, a large variety of such gadgets would be necessary to fit the many types of lighting equipment now in use. Secondly, such gadgets to be safe and not subject to misuse would likely have to be made of metal or plastics, and thus use much essential material. In the third place, they could not be readily recognized by air raid wardens as approved, and therefore safe, blackout units. Fourthly, a device that might be safe with one size bulb could easily be dangerous when used with a larger bulb or give insufficient light if used with a smaller one. Fifthly, if made of paper or similar material it would be easy for the thoughtless user to enlarge the light-emitting opening, involving danger of detection from the air. And lastly, if insufficiently ventilated they might involve some fire risk.

In certain areas where all-night blackouts are ordered every night, it is obvious that people will not be content to spend their time in one obscured well-lighted room. Neither is it practical to obscure the entire house. To do so would require the use of blackout materials in such quantities as to seriously handicap the war program. The introduction of the blackout lamp, therefore, even though it is a new type of lamp not useful for any other purpose and does require some essential materials, will result in greater overall conservation of materials than would complete obscuration of large numbers of residences.

While the specification for indoor blackout lamps has been issued, the War Production Board's amended Order L-28, part 1049, states that they may be produced only in accordance with specifications approved by the U. S. Army and Navy for delivery to or for the account of the U. S. Army or Navy, the U. S. Maritime Commission, the War Shipping Administration, the Panama Canal, or by specific authority granted by the Director of Authorizations. Manufacturers must submit samples of their product to the Electrical Testing Laboratories, in New York, for test to determine whether it complies with the specification. When this has been found to be the case, the Electrical Testing Laboratory notifies the Army Engineer Board, which in turn notifies the manufacturer that the lamps can be placed on the market, the lamps to be marked "Indoor Blackout—War Dept. Standard," followed by a code number. There are other blackout lamps on the market which do not comply with the specification, and they cannot bear this marking.

Special Equipment.

Naturally as a result of all this research work many new types of equipment were developed and tested. For example, the traffic-control baton (Figure 11) consists of a flashlight equipped with a lucite rod about one foot long with an arrowhead on the end of it. This was used to direct traffic, but is now obsolete.

Another portable traffic-control device, which is now obsolete, was a pair of shoulder epaulettes (Figure 12). These consisted of a small square box worn on each shoulder showing red to the front and rear, and green to the sides. The traffic officer wearing such a device, which was operated by dry batteries attached to the belt, merely faced in the direction he wished to stop traffic. In other words, this was really a portable traffic-control signal.

There have also been developed a dry-battery-operated light for fixed signs, special battery-operated railroad-crossing and whistle-post signs, and temporary changeable letter signs.

A special device (Figure 13) consisting of a single-cell dry battery with a small lamp and reflector and means of attaching it to essential signs was developed for use during blackouts. Experimental equipment (Figure 14) for studying materials and means for obscuring * windows during blackouts has also been developed.

Luminescent Materials.

There is one phase of blackout that we have been hearing a good deal about lately, and that is the use of luminescent paints and materials. These are available in two types: the radio-active or self-energizing type, and the group that requires some external or separate source of energy to activate it. They have many uses, particularly for the purpose of guiding people in darkened places and as protection against running into obstructions. Such material is also used in the form of clothing for the protection of the wearer. Here, again, there are technical problems involved, such as the relation between the energy absorbed and the duration and relative brightness of the afterglow. The question as to the relative effectiveness of different wavelengths in energizing such materials, etc., has not been completely answered. No small amount of research has been done here in co-operation with the manufacturers of the materials. Unfortunately, radio-active, fluorescent, and phosphorescent materials are rather expensive, and that limits what otherwise might be a wider application to blackout conditions. In their present forms they are not generally to be recommended for continuous use out of doors.

Portable signs and blackout photoflash lamps (Figure 15) for taking night pictures on infrared films without being visible from the sky have been developed.

Publicity.

The Office of Civilian Defense is the official governmental agency for distributing information regarding blackouts. They have published excellent bulletins on various phases of the subject. A list of some of the more important bulletins available from the local OCD, or from the Superintendent of Documents, Washington, D. C., is given at the end of this article.

* I. E. S. Transactions, Vol. 37, No. 8, September, 1942.

Here and Abroad.

Perhaps some are wondering why it is taking so long to solve all these problems. It may be reasoned that England has by now solved most of them. So she has—for England, but conditions and equipment are vastly different in America. While we have the advantage of England's experience and developments, their practice must be widely modified in many instances to meet American conditions, and that is being done as rapidly as practical.

Many of these matters are covered in the recently issued War Department specification, "Blackout of Buildings."

As a result of all of this work War Department specifications have been issued for:

(1) Streetlighting During Blackouts.
(2) Blackout Requirements for Highway Movement.
(3) Blackout Flashlights, Lanterns, and Flares.
(4) Blackout of Buildings.
(5) Luminescent Materials.

Specifications for traffic control during blackouts and the blackout of railroads are under preparation.

After such specifications are prepared covering the lighting requirements they are submitted to various manufacturers of equipment in order to make sure that it is practical to produce equipment that will give the results specified. The specifications are then reviewed by various governmental departments at Washington and are now either issued or will be shortly.

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MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

CELLOPHANE BUBBLES.—Pacific Marine Review for January, 1943, published the following interesting description of "Bubblfil", a new material now being manufactured by E. I. du Pont de Nemours & Co.:

Sleeping on Air—air wrapped in tiny cellophane packages—approaches realization.

For chemists have accomplished the feat of trapping air in a continuous stream of cellophane bubbles. The resiliency and buoyancy of the resulting product open up a large field of interesting possibilities for its application.

Tests already made show that the cellophane bubbles are fully as buoyant as the imported kapok, which comes from the seed pod of a Javanese tree. The new product has been considered for life-jackets of the type worn by U. S. Navy personnel, for which kapok heretofore has been used. "Bubblfil" has also been tried in the air compartments of lifeboats and life-rafts, where kapok is no longer being used because of the limited supply. It is

also proposed for bridge pontoons, formerly filled with sponge rubber. If these air compartments are punctured by bullets or falling debris, the "Bubblfil" will keep the craft afloat. It has proven entirely satisfactory as a replacement for kapok in aviation tow targets, where buoyant material is used to keep the targets afloat when they are shot down.

Neither kapok nor cellulose bubbles can be classed as nonflammable, but the bubbles will not ignite when struck by tracer bullets. This gives "Bubblfil" a distinct advantage in military applications of many kinds. It is even possible to render "Bubblfil" flame-resistant by chemical treatment.

In life-jackets or life-rafts "Bubblfil" has another advantage, for it loses buoyancy less rapidly than kapok upon prolonged immersion in water. Tightly packed "Bubblfil" weighs about 1.5 pounds per cubic foot and will support 20 to 30 times its weight. Less than three pounds of the material will keep a heavy man's shoulders out of water. The bubbles cannot be broken by squeezing, nor will they rupture at the extremely low pressures of high altitudes. The bubbles remained intact in laboratory tests equivalent to an altitude of over 50,000 feet. The material also is quite stable to extremes in temperature. Heating for three days in air at temperatures above 200 degrees F. and chilling to 28 degrees below zero Fahrenheit did not break the bubbles.

The material is so tough that its buoyancy was not affected when cheesecloth bags filled with it were subjected to an impact of 79 foot-pounds per square inch, equivalent to the impact sustained by a life-jacket worn by a 200-pound man upon striking the water after jumping from a height of 55 feet.

The resiliency of the cellophane bubbles, a property derived from the "springiness" of the entrapped air, has encouraged the Du Pont Company to study their suitability as a shock-absorbing material. Here "Bubblfil" might replace sponge rubber or so-called "cellular rubber," so very scarce today. The "Bubblfil" has been formed, by means of an adhesive material, into mats and cushions. These might be used for padding in airplanes or tanks. Bullets will not shatter them, leaving only small holes.

A third important characteristic of "Bubblfil" is its low thermal conductivity, that is, its insulating property. Air is a good insulator. "Bubblfil" is a mass of air cells, and can be used as a stuffing and as an insulating layer. Experimental fabrics have been woven, with cotton thread running one direction and strands of "Bubblfil" in the other. This extremely lightweight material could be used as an interlining for cold-weather jackets or flying suits, or several layers could be used as the filler for sleeping bags.

Chemically, "Bubblfil" is the same material as cellophane or rayon, namely, regenerated cellulose made by the viscose process. The syrupy viscose material is extruded through a single spinneret hole, relatively large in size. A small amount of air is injected into it at regular intervals just as the filament is coagulated by the acid bath in which it is being spun.

The size and spacing of the bubbles, which are streamlined in shape, may be arranged according to choice. Much of the bubble-strand now being made has bubbles a little more than a quarter of an inch long, running three to the inch. A smaller size is also made. The material greatly resembles a string of transparent beads.

THE PHYSICAL BASES OF SEIZURE.—Mr. E. A. Smith indicates in this article some of the salient features of seizure, or, more exactly, the conditions leading up to seizure. Generally speaking, seizure is a symptom

of inefficiency. Mr. Smith's article was published in the December 18, 1942, issue of Engineering.

Much work has been carried out on the seizure of metallic faces in the presence of, and without, lubricants. In view of the importance of the subject to industry at present, where mechanical equipment is subject to sustained loads and working periods, a short review of the physical process of seizure, with some suggestions for discouraging its onset, may be of value.

There is clearly a direct relation between the metallurgical nature of a surface, its physical condition, that is to say, its surface finish, and the tendency of that surface to seizure. The relation between load and seizure, or breakdown, is more complicated, however, by the recovery from seizure which rubbing faces exhibit. Clayton, in his paper on "The Use of the Four-Ball Extreme-Pressure Lubricant-Testing Apparatus for Ordinary Lubricants," * has well illustrated this recovery from seizure, and points out that certain additives, as for example, extreme-pressure additions, show to advantage in this respect. As a general statement, it might be said that seizure between two metallic faces is preceded by a rapid rise in temperature. Blok † has examined the temperature factors theoretically, and Figure 1, taken from his paper, "Theoretical Study of Temperature Rise at Surfaces of Actual Contact under Oiliness Lubricating Conditions," illustrates the elements of the problem. It will be seen that, when one surface passes over another, the temperature of the faces tends towards a wave form; the same applies to projections, but the rise in temperature is then more abrupt.

Bowden and Leben ‡ have examined the problem from the practical aspect in the laboratory, and have drawn attention to the "stick-slip" mechanism, which they consider to be a normal feature of metallic friction. In effect, they found that, when two metallic faces rub over one another at relatively low speeds, the high spots on opposite faces tend to pierce the oil film and to weld together. The high spot on the face with the lower melting point momentarily fuses to one on the opposite face, and the junction is then ruptured by the continued movement of the faces. This is an effect on a micro-scale, and is repeated, resulting in sticking and slipping. It is the sum total of the violent spasmodic variations in friction that result which gives the overall coefficient for the faces in contact.

When a high spot melts on a face, the temperature does not increase further. Consequently, if a metallic surface with a relatively low melting point is operated against one which is both harder and has a higher melting point, the maximum temperature which might be expected at the interface would approximate to the lower melting point. This is one of the reasons why a relatively soft material like white metal is used in conjunction with, for example, steel. The stages which lead up to seizure are outlined below in sequence. The first may be described as a normal phase and lends itself comparatively easily to accurate observation. The second phase, in which the oil film tends towards the boundary state, exhibits more variable results. The third, or pre-seizure phase, is not only difficult to follow, but may give variable and unpredictable results.

To understand the mechanism of seizure, it is advisable to go back to the origin. Figure 2, given by G. L. Neely in a paper on "Friction and Wear Comparisons for Lubricated Surfaces," § expresses, in its simplest

* General Discussion on Lubrication and Lubricants, Vol. 2, page 274. London: The Institution of Mechanical Engineers, October, 1937.
† Ibid., Vol. 2, page 222.
‡ Proc. Roy. Soc. A., Vol. 169, page 371 (1939).
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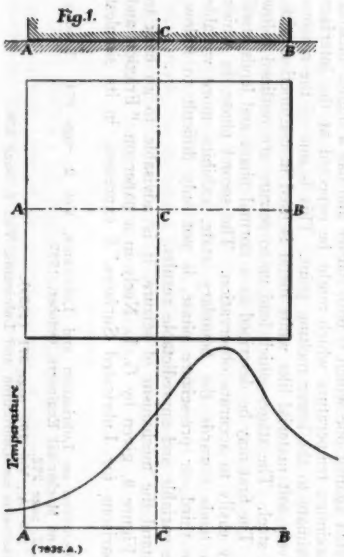


Fig.1.
A
C
B
Temperature
(7935.A.)

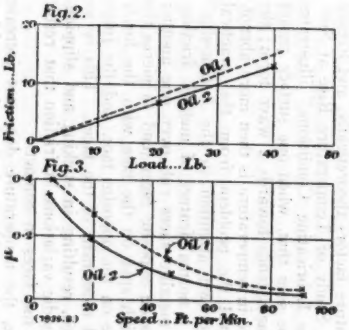


Fig.2.
Friction...Lb.
Oil 1
Oil 2
Load...Lb.
Fig.3.
Oil 1
Oil 2
Speed...Ft. per Min.
(7935.B.)

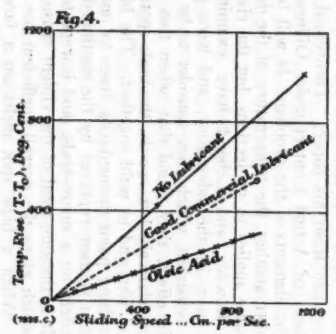


Fig.4.
Temp. Rise (T-T0) Deg. Cent.
No Lubricant
Good Commercial Lubricant
Oleic Acid
Sliding Speed...Cm. per Sec.
(7935.C.)

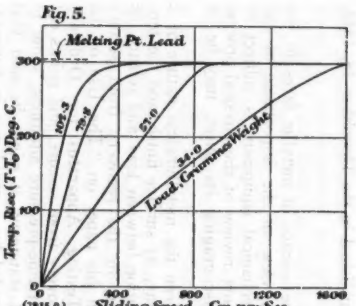


Fig.5.
Melting Pt. Lead
107.3
79.8
57.0
34.0
Load, Grammes/Weight
Temp. Rise (T-T0) Deg. C.
Sliding Speed...Cm. per Sec.
(7935.D.)

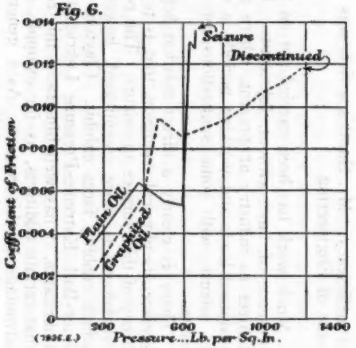


Fig.6.
Seizure
Discontinued
Plain Oil
Graphited Oil
Coefficient of Friction
Pressure...Lb. per Sq. In.
(7935.E.)

form, the relation between load and friction for a straight mineral oil lubricating steel against bronze with a rubbing speed of 3.6 feet per minute at a temperature of 175 degrees F., the duration of the test being 8 hours. The relation between rubbing speed and friction cannot be expressed in linear form, and is given in Figure 3, for a load of 500 pounds per square inch under similar test conditions to the above. These curves illustrate the ideal operating condition, that is to say, with such factors as vibration, spasmodic loads and external heat sources absent. The accumulation of impurities in the oil or grease used for lubrication has not been considered; but it is the state which, if maintained, would ensure an absence of seizure at all times.

The increase of surface temperature determined by Bowden * is reproduced in Figure 4 for constantan sliding on mild steel with a load of 102 grams. This indicates that the so-called "normal" or full fluid conditions of lubrication do not exist in practice. How important is the effect of soft metal against a harder one is well illustrated by Figure 5, also due to Bowden, from which it is seen that the temperature rise is limited by the melting point of the lead—a reminder that the selection of bearing metals is an important factor in offsetting seizure. With regard to such factors as vibration, attention should be drawn to the more recent work of Bowden and Tabor on the impact strength of lubricant films. They consider that vibration enables high spots to pierce the oil film more easily, which suggests that something more than a simple load test is required for a lubricant.

It is doubtful whether fluid oil-film conditions obtain in a bearing for any length of time. What is considered to be fluid friction in practice is probably the combination of both boundary and fluid-film conditions, the latter predominating. A journal bearing free from vibration, where a full oil wedge has been established, affords the nearest approach to sustained fluid-film conditions, bearing in mind the above qualifications. On a reciprocating face, however, boundary conditions will predominate. Finch and Zahoorbux, in their "Study of Wear and Lubrication by Electron Diffraction," † have thrown light on the conditions which exist on a mild-steel face with so-called fluid-film conditions of lubrication, indicating the existence on the steel of a flowed layer, to which the late Sir George Beilby first drew attention. This illustrates the proximity conditions to metal pick-up, and might be interpreted as according with the works of Bowden and his collaborators. Whether the flowed layer is amorphous or not is still a subject for debate, but the experimental evidence from the above and other sources favors the view that the superficial metal on a rubbed surface is melted by pressure or heat, or both. Blok ‡ has pointed to the temperature flash between gear teeth, quoting a value of 250 degrees C., which lends further support to the possibility of localized welding or fusion taking place between opposite high spots and of the ease with which this condition can be extended to more general welding or seizure.

From the above it is clear that the seizure state is near at hand in the average bearing, and does not require a large increase in load to make it a disturbing influence in mechanical efficiency. If typical curves are examined for friction plotted against load up to seizure point, it will be noticed that the seizure of a bearing face is frequently preceded by a drop in friction. Two explanations may be offered. When the fluid film between the faces is broken down by pressure, an adsorbed film is left. This heats up and becomes highly fluid, so that friction falls. The resistance of

* Ibid., Vol. 2, page 236.
† General Discussion on Lubrication and Lubricants, Vol. 2, page 295.
‡ Ibid., Vol. 2, page 14.

this boundary film to removal depends upon the degree of adsorption which has occurred, its temperature characteristics, and other working factors. Work carried out at the National Physical Laboratory in 1933 revealed that castor oil, in continuous running, exhibited a seizing temperature in excess of 250 degrees C. at 2000 pounds per square inch at 40 Rpm. At lower speeds, a still higher seizing temperature was recorded, and the suggestion was made that repeated approaches to seizure formed a boundary film of oil, which could withstand abnormal loads.

The modulus of elastic rigidity usually decreases rapidly with increasing temperature, reaching a minimum at the fluid or melting point of the metal. This would mean that a minimum rigidity is reached just before full seizure, and friction would again fall. A low capacity for deformation in a bearing alloy renders it more liable to early breakdown, as, for example, in lead bronze. The increasing use of lead flashes, cadmium and silver bearings, etc., points to the value of easy deformation. Incidentally, it should be remarked that certain of the temperature figures quoted above may not be true surface-metal temperatures, but an average bearing value. Thus, if a general temperature of 100 degrees C. is recorded in a bearing, it can be reasonably assumed that the temperature of the surface layers of the rubbed metal is far in excess of this figure. N. K. Adam's contribution to the General Discussion on Lubrication, on the subject of "Molecular Forces in Friction and Boundary Lubrication," * contained some interesting observations on the efficiency of local welding of high spots; he pointed out that, in a surface moving at 100 centimeters per second, the high spots being, for example, 0.1 millimeter across, the time of contact, during which welding occurs, is only 0.0001 seconds. If the temperature rises over larger areas, welding becomes general and seizure sets in.

Reverting to the stages which lead to seizure, the capacity for recovery of a metallic face can play an important part. Mild steel can flow plastically without seizure, as has been indicated by Finch and Whitmore,† who observed how colloidal graphite could be rolled into the superficial layers when used in the oil for lubrication. The presence of lead in a hard alloy, such as lead bronze, gives that material a certain capacity for surface deformation, when some of the lead on the surface layers has been withdrawn and wiped over the rubbing surfaces. That the lead cannot function fully when occluded in the alloy is indicated by the difficulty of initially running-in such a bearing material. While, as stated, seizure is not far off in a rubbing face, particularly during reciprocating movement or at slow speeds, such a face should not seize fully unless neglected. The remedy is selection of the right lubricant.

The behavior of metallic surfaces themselves, of fluid lubricants, and the part played by additives has been studied in some detail. The formation of an oxide layer can prove helpful in certain circumstances, the detritus acting as a parting medium; but usually the oxide is harder than the original metal, and, while the capacity for extensive welding or seizure may be reduced, wear and scoring would be increased. A large number of oil-soluble and insoluble compounds have been examined by Brownsdon ‡, Evans § and others, and the general conclusion that might be drawn is that a chemical combination between the compound and the metallic face is necessary to offset seizure at high loads or extreme pressures. Thus, the presence of sulphur is considered to bring about indirectly the formation

* General Discussion, Vol. 2, page 197.
† "Graphoid Layer on Bearing Surfaces," by Professor G. I. Finch and E. J. Whitmore. Engineering, Vol. 146, page 91 (1938).
‡ General Discussion, Vol. 2, page 254.
§ E. A. Evans. Jl. Inst. Petroleum, May, 1941.

of a metallic oxide, although it is held by some that a sulphide is formed, which provides the parting action. In the past few years, there has been developed a wide range of extreme-pressure additives, which, however, have for their function the offsetting of seizure at high loads.

Medium-high loads and normal loads are met with in such equipment as engines, machine tools, journal bearings and certain classes of gears, which go to make up the major part of industrial mechanical equipment. The E. P. addition to an oil is not usually considered necessary for this work. Adam pointed out, in the paper previously quoted, the value of interposing graphite slip planes between rubbing faces in this class of lubrication; graphite slips with facility along its basal plane when rubbed, and thus provides lubrication. The interposition, therefore, of a graphite particle between two high spots which tend to make contact, forms a natural series of slip planes between the metal points, and so cleavage takes place in the graphite and not in the metal. Hughes and Whittingham * and Fogg and Hunwicks † have also drawn attention to this, the former investigators finding that lower friction is produced at low speeds, and the latter that static friction is reduced thereby. The value of this practice is indicated by the wide use of colloidal graphite in oil during the assembly and running-in of mechanical equipment. Shaw ‡ has published various seizure tests showing the value of colloidal graphite in this connection, and a typical curve for lead bronze is illustrated in Figure 6. To ensure an adequate supply of graphite particles on a metallic face when most needed, the practice has been adopted of assembling equipment with oil containing a high percentage of colloidal graphite.

No reference has been made in the above notes to the influence of surface finishes on the proneness or otherwise of bearing surfaces to seizure. The correct finish cannot be stated arbitrarily without reference to the type of alloy being used and the operating conditions. In certain cases, a fine finish is obviously desirable, although it has been pointed out that two fine or superfine finishes in contact may not be as satisfactory as a superfinish rubbing against a ground face; that is to say, a fine finish against a coarser one, the latter providing the deforming superface. Then again, the direction of finish marks has an influence on the continuity of the oilfilm, as revealed by Trillat § a cross hatch being superior to parallel finish marks. In general, it might be said that finish marks at right angles to one another on opposite faces would be preferable; that is to say, in the case of a journal bearing, from the theoretical point of view at least, the shaft should be turned and the bearing broached. This may be difficult to achieve in practice, although it should not present an obstacle in plane faces, such as machine-tool slides.

These notes are not put forward as a complete survey, but merely as an indication of some of the salient features of seizure, or, more exactly, to the conditions leading up to seizure. When equipment is new, the precautions necessary to avoid seizure are self-evident: cleanliness of bearing surfaces, adequate lubricant on them before assembly, and careful initial operation—it being assumed that a satisfactory finish and clearance have been ensured. More lubricant is required during initial operation after assembly, for extra cooling and to carry away swarf or other impurities. When equipment has been satisfactorily run-in, the main feature to watch is the temperature during running on sustained loads, while adequate maintenance is not only wise but necessary where a run bearing or scored shaft may be difficult to

* Trans. Faraday Soc., January, 1942, Part I.
† Jl. Inst. Petroleum, January, 1942.
‡ The Machinist, March 19, 1938.
§ J. J. Trillat and R. Fritz (Jl. Chimie Phys., Vol. 34 (1937).

replace. Generally speaking, seizure is a symptom of inefficiency, for lubricants, even in the present restricted number of grades, are adequate. Where overheating is due to high and sustained loads which cannot be avoided, reinforcement of the oil as indicated above can be carried out to advantage.

COLUMBIUM IN HIGH TEMPERATURE STEELS.—This condensation of D. W. Rudorff's article in Metallurgia, October, 1942, is reprinted from Metals and Alloys, January, 1943.

In recent investigations, E. R. Parker has found that certain intermetallic compounds are more stable at high temperature than carbides; and that alloys containing precipitates of such compounds possess a greater resistance to deformation and fracture than commercial alloys, relying upon carbides for their strength. His experiments with a 3 per cent Cb, 97 per cent Fe alloy are noteworthy. Similar investigations in Germany have resulted in the development of low-alloyed columbium steels for high-temperature service.

Iron-columbium alloys with more than 0.5 per cent Cb can be hardened by quenching from high temperatures and subsequent tempering, because the solubility of the intermetallic compound formed increases with rising temperature. Tests with an alloy containing 1.9 per cent Cb show that hardness rises steeply from 900 degrees C. (1652 degrees F.) and declines at temperatures exceeding 1150 degrees C. (2102 degrees F.). This is due to the different solubilities of columbium in the gamma-phase and the alpha-mixed crystal and in the gamma-alpha transformation after quenching, and the fact that at 1150 degrees C. (2102 degrees F.) the alloy enters the delta-phase and that the homogeneous delta-mixed crystal is not subject to transformation during quenching to room temperature.

In testing the influence of the temperature of draw upon the hardness with various temperatures of quench, it was found that the optimum precipitation temperature lies between 600 and 650 degrees C. (1112 and 1202 degrees F.) and that, a 1300-degrees C. (2372 degrees F.) quench obtains the greatest hardness.

This property of columbium finds extensive employment in stainless chromium-nickel steels where its addition reduces the danger of intercrystalline corrosion. It can also be used to reduce the hardness of chromium steels which must not be hardenable. Columbium, to eight times the carbon content is required for combining the carbon content.

With a steel containing 0.13 per cent C. and 1.04 per cent Cb, the hardness can be increased from 87 to 99 Brinell with quenching from 1100 degrees C. (2012 degrees F.) Quenching from 1200 or 1250 degrees C. (2192 or 2282 degrees F.) shows still greater hardness. Columbium carbides brought into solution at high temperature are precipitated only with the temperature of draw exceeding 500 degrees C. (932 degrees F.). Decrease in hardness occurs only when a temperature of 650 degrees C. (1202 degrees F.) is exceeded.

This high resistance to tempering can also be produced with steels in which the columbium percentage is more than eight times that of the carbon. When the columbium carbon ratio exceeds 8:1, the creep strength shows a rapid rise, due to the existence of the intermetallic compound of iron-columbium in addition to the columbium carbide.

Impact strength rises with tempers at 550 degrees C. (1022 degrees F.) and higher but above 550 degrees C., creep strength rapidly decreases. In-

creased yield point and creep strength, therefore, must be purchased at the expense of notched-bar impact strength. Impact tests on plain bars without notch showed good impact values.

The same heat treatment can be applied to alloyed steels if the columbium content is higher than 8 times the carbon percentage.

Additions of columbium, with columbium more than eight times greater than carbon, to austenitic high temperature resistant steels, results in improvement of creep strength. Addition of columbium beyond a certain upper limit effects changes in the structure of highly alloyed chromium-nickel steels. Restitution can be effected only by increasing the nickel content. Existence of the critical 8:0 ratio was also found in the case of rolled material not subjected to heat treatment.

Any increase in columbium above 2 per cent is useless as it will not be accompanied by further improvement in creep strength. Less than 2 per cent permits the use of high quenching temperatures without producing the delta-crystallites. A reduction in columbium content to 1 per cent will not effect a reduction in creep strength, provided the carbon content is also reduced to the greatest possible extent. The favorable influence of increased carbon content in steels containing 2 per cent Cb and more is solely due to the fact that it tends to shift the gamma-delta transformation to higher temperature ranges.

Minimum permissible columbium content lies between 0.5-0.7 per cent. Erratic decreases in creep strength in steels containing less than 0.5 per cent Cb showed the beneficial effect of the intermetallic compound was negatived by some factor which was finally found to be the sulphur content. A reduction of sulphur to 0.01 per cent, which can be achieved by special methods, results in only a slight reduction in the creep strength qualities.

SOLAR RADIATION AS A POWER SOURCE.—This article by C. G. Abbot, Secretary, The Smithsonian Institution, was published in Military Engineer, February, 1943.

This major power source of the world is as yet almost unused by engineers. The intensity of solar radiation at mean solar distance outside the earth's atmosphere is about 1.94 calories per square centimeter per minute. Expressed in English measures this is 7.16 Btu. per square foot per minute. Actual supplies of sun heat, however, vary with the season. Owing to the ellipticity of the earth's orbit we are about 3,000,000 miles nearer the sun in January than in July, and the actual intensity of the sun's rays outside the atmosphere is about 6 per cent greater in January than in July. As there is less humidity and clearer air in winter, it follows that the sun's heat at the earth's surface in the Northern Hemisphere is a good deal more intense in winter than in summer for equal solar altitudes above the horizon. The reason winter is cold is because the sun lies so far south that its rays shine very obliquely, so that the average intensity on a horizontal surface is thereby greatly reduced.

Thick clouds reflect away about 75 per cent of the sun rays which strike them. Much of the area east of the Mississippi is 50 per cent cloudy, so it follows that in these sections a third of the sun's radiation is reflected out to space. Besides this cloud loss there is an actual absorption by the water vapor and other ingredients of the atmosphere. This amounts in humid localities to from 15 to 25 per cent. Accordingly solar power propositions

would operate at great disadvantage in most of the States east of the Mississippi, excepting Florida, as compared to the arid and generally high-altitude regions of the Southwest.

Measurements of solar radiation made at the earth's surface upon a receiver at right angles to the beam, and with the sun at 15 degrees or more above the horizon, range from 1.5 calories per square centimeter per minute down to 1.0 calorie, or even less, depending on the clearness of the atmosphere. In favorable localities a value of about 1.35 calories may be assumed as the average for the day of solar energy on a surface normal to the beam, except while clouds obscure the sun. This corresponds in ordinary power units to 1.15 horsepower per square yard.

Whether or not it is worthwhile to employ the solar energy for power depends on the efficiency which can be achieved in converting solar radiation into mechanical energy. On that factor depends the size and cost of the equipment. An efficiency of only 1 to 5 per cent would be apt to involve prohibitively cumbersome and costly equipment. But a solar engine with an efficiency of 10 to 15 per cent might be commercially competitive with other sources of power, even at present. As time goes on, it is to be supposed that the cost of the major power sources, coal and oil, will rise, though the limited supply of water power may remain relatively unchanged in cost. Hence, in the future, unless some as yet unused source of power becomes important, it is probable that solar power will be extensively employed.

If such a change in the major sources of power should occur, it would tend to alter very much the distribution of population. Such a State as New Mexico would become a great manufacturing center. With machines of the type already devised, that State could furnish from solar radiation more power than is now used for heat, light, transportation, and manufacturing in the United States, and at a cost not perhaps exceeding the present cost of power from coal.

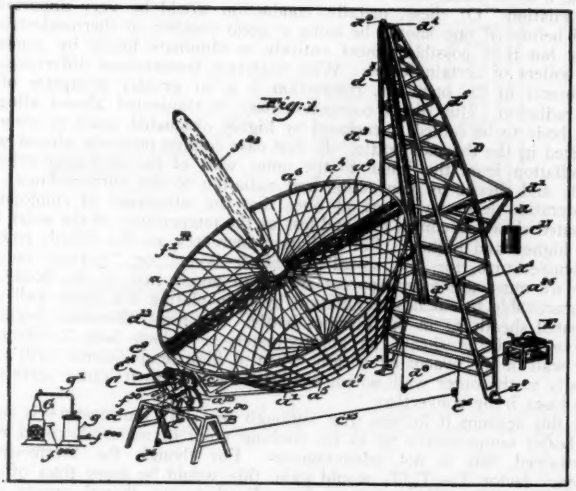
There are two major difficulties in the way of utilizing solar radiation. First, except on overcast days, the sun's rays come from a moon-sized spot, which moves daily through the sky from the eastern to the western horizon, and yearly from 23 degrees north to 23 degrees south of the celestial equator. Second, from sunset to sunrise the sun's rays are wholly cut off.

Early Experiments.

In one interesting series of expirements, reported by Willsie and Boyle in Engineering News, May 13, 1909, the first difficulty was avoided by employing a stationary horizontal receiver. This, however, is at great cost in thermodynamic efficiency, owing to the low temperatures of operation, and to losses of radiation by reflection, due to the very oblique incidence of the rays during many hours of the day and year. It would seem fatal to sacrifice so much efficiency.

The work of Shuman at Tacony, Philadelphia, also reported in that same issue of Engineering News, led on at length to the very different experiments of Eastern Sun Power, Ltd., described by Ackermann in the Smithsonian Report for 1915. These experiments came nearer being a commercial success, I believe, than any others on solar power up to that time. A large plant was erected near Cairo, Egypt, and used for a time for irrigation from the Nile. It appears to have been abandoned during and since the World War of 1914-1918. In these experiments the sun's rays were roughly focused upon boilers, and thus from the thermodynamic viewpoint more eligible temperatures were attained than those of Willsie and Boyle's experiments.

Some inventors have attempted to employ thermoelectricity or photoelectricity as means of escaping from the necessity of working through gaseous heat cycles to achieve mechanical motion. It is difficult to conceive that thermoelectric couples could ever be a valuable expedient for this purpose. The electromotive forces available are so small that the multiplication of couples is necessarily great, and the apparatus required would contain enormous numbers of parts. The wires used would all be metallic



ENEAS SOLAR GENERATOR, PATENTED 1901.

conductors of heat, so that a very large fraction of the solar input would be dissipated in useless heat loss. As for photoelectricity, it seems to be limited to comparatively narrow regions of the spectrum, so that large fractions of the solar rays would be wholly useless to these devices. Of the remaining useful rays, no inconsiderable part would be converted into heat, and would also be useless. I can not think that at present these direct electrical conversions of solar radiation seem promising solutions of the solar power problem.

INSTRUMENTS.

Within the past quarter century, so much progress has been made in the commercial use of aluminum products, and also of high vacuum technique, that it is possible for one who is familiar with the astronomers' solutions of their problem of following the heavenly bodies with telescopes to design types of apparatus for utilizing solar radiation for power, combining minimum expense with maximum efficiency.

Formerly the choice for solar mirrors lay between mirror glass and metals of rather low reflecting power and short reflecting life. Such materials for mirrors were heavy, costly, inefficient, and quickly deteriorating.

We can now purchase commercially the bright reflecting product called "Alcoa" in thin sheets of large size. It is a special preparation of aluminum, long retaining its reflectivity, and with a coefficient of reflection for solar rays slightly exceeding 80 per cent. Frames of suitable curvature being made from duralumin shapes, these may be covered with the thin "Alcoa" sheets to make up cheap, light, and fairly permanent solar mirrors.

In consideration of best design, we come to the question of waste of heat. It is well known that heat is lost by three processes: conduction, convection, and radiation. Of these, metallic conduction would be very important, as stated before, if one should be using a great number of thermoelectric elements, but it is possible almost entirely to eliminate losses by conduction with boilers of certain forms. With moderate temperature differences, and for objects in the open air, convection is a far greater dissipater of heat than radiation. But direct convection may be eliminated almost altogether if the body to be cooled is enclosed by highly evacuated space as commonly practiced in the thermos bottle. In that case cooling proceeds almost wholly by radiation from the inner to the outer wall of the enclosing evacuated sheath, and thence by convection and radiation to the surroundings. This consideration leads us to see at once that the advantage of employing an evacuated sheath becomes less and less as the temperature of the solar boiler rises higher and higher. For radiation increases as the fourth power of the temperature for the so-called "black body" or "perfect radiator." Since we must use a transparent sheath to admit rays to the boiler, it is not practicable to cut down radiation by fully plating the inner wall of the evacuated sheath, as in the thermos bottle. We must, therefore, regard the inner wall of the sheath as approximately a "black body." Hence the inner wall of the evacuated sheath, when at high temperatures, will radiate strongly to the outer wall, which conducts the heat to its outer surface, and there loses it by convection.

On this account it follows that although the sun's temperature is so high that boiler temperatures up to the melting point of materials could readily be attained, this is not advantageous. For though the thermodynamic efficiency factor $T_1—T_2/T_1$ would gain, this would be more than offset by the increased heat losses of the boiler. Furthermore, though quartz glasses like "Pyrex" enable us to use transparent evacuated sheaths at fairly high temperatures, high vacua lose their excellence with very high temperatures, so that convection becomes serious.

On these accounts it is not desirable in solar power machines to employ boiler temperatures much above 200 degrees C. (392 degrees F.). If operating to a condenser at 30 degrees C., such a temperature of the boiler gives a thermodynamic factor of 473—303/473 = 36 per cent, which, for reasons just explained, may be regarded as the maximum to be expected if a due regard is paid to loss of heat from the boiler.

Another fundamental consideration in designing solar power devices is that the loss of heat from a body through convection or radiation is directly proportional to the external area of the surface of the body. Hence it is of importance for diminishing the waste of heat that the boiler surface should be as small as possible, by using fairly accurate optical mirror forms.

Astronomers have long ago agreed that the simplest mechanical motions that could be devised for following celestial objects are those of the equatorial telescope. This scheme involves mounting the instrument which is to follow the celestial object upon an axis parallel to the earth's axis, and imparting to this "polar axis" a uniform motion of 15 degrees per hour. If the instrument is to be adapted to follow objects at different distances north or south of the celestial equator, that is of different declinations, there must be a second axis at right angles carried by the polar axis. This sec-

ond axis called the declination axis, carries the telescope or other following device, and is to be set by hand to the position of any desired celestial object, and clamped there. If the sun remained stationary with regard to the celestial equator, no second axis would be needed in solar power machines. But the sun travels through 47 degrees north and south during the year.

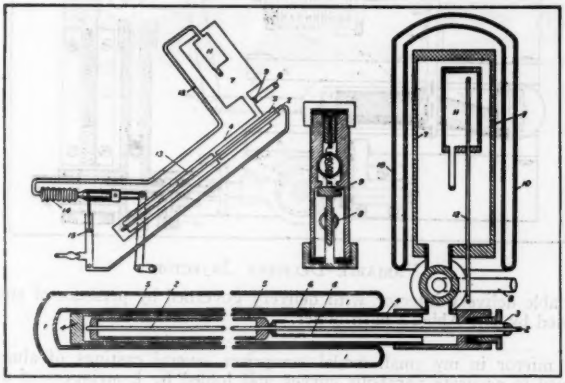
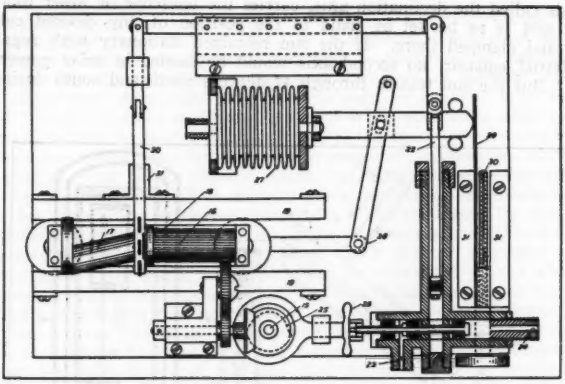


DIAGRAM OF "FLASH BOILER".

Flash boiler 4, in vacuum sheath 1, served by water supply 2, governed by air pressure in steam chest 7, operating extensible chamber 14, governing injector 15.

It is highly desirable to operate with a stationary boiler. The withdrawal of steam from a moving boiler involves costly and unsatisfactory connection. It is clear that a spherical boiler placed in the intersection of the two axes of an equatorial mirror mounting could be stationary. But it would be impossible to enclose thoroughly with an evacuated sheath. The mirror in this case would be circular and preferably of parabolic curvature, which is an awkward shape for fabrication.

It has seemed to me preferable to neglect the north to south motion of the sun, using a mirror rotating uniformly at 15 degrees per hour about a single polar axis. The boiler then becomes a tube of small diameter lying in the axis. The vacuum sheath is an elongated "Pyrex" thermos bottle, of which about one-third the circumference of the outer surface of the inner wall is gold plated. The mirror is a rectangular concave cylindric mirror, of parabolic curvature, whose equation, as I prefer it, is $y^2 = 36x$. The mirror is long and narrow, and rotates about its focus, the polar axis. Being long compared to its width, the deliberate end-loss of light at the solstices, June 20 and December 20, from neglecting the sun's motion in declination, is not serious, and this loss becomes zero at the equinoxes. The metallic boiler tube is blackened by painting with a suspension of lampblack in alcohol with a silght addition of shellac. At the low temperatures, not exceeding 200 degrees C., this paint does not burn. It absorbs about 95 per cent of the solar radiation.



VARIABLE DELIVERY INJECTOR.

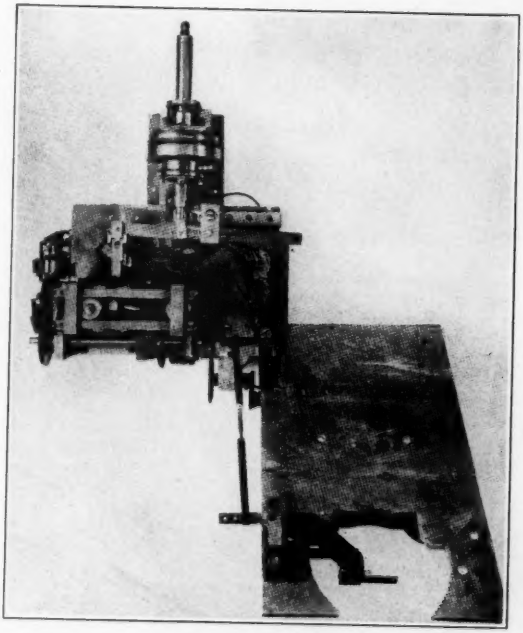
Variable delivery injector with delivery governed by pressure of steam as first used by Dr. Abbot's flash boiler.

The mirror in my small model comprises several castings of aluminum, machined to accurate parabolic curves and joined by L stringers of duralumin to form a cradle. To this cradle are attached "Alcoa" sheets not previously bent, and held down by narrow metal straps screwed through the sheets to the parabolic frames. At the ends the mirror frame supports steel hanger bars which carry hollow trunnions, and supports above a counterbalance bar of metal, set edgewise to the beam and extending from end to end of the mirror as a stiffener. Simple stout wooden posts, set in the ground, are adapted to carry rollers on which the trunnions rest with their axis parallel to that of the earth. The elongated "Pyrex" thermos bottle enclosing the boiler tube rests axial to the hollow trunnions, and is closed at the lower end.

To drive the mirror most conveniently, a worm and wheel mechanism is attached to one end of the mirror and its support. The worm is driven at the correct speed by a tiny 60-cycle electric motor. Where alternating electric current is difficultly available, a weight drive may be substituted, regulated by an escapement controlled by an ordinary alarm clock. I have used such a contrivance successfully for a large mirror on Mount Wilson.

For solar power, I prefer the "flash boiler" principle because of its economy of fair skies. Even in the desert regions, cumulus clouds occasionally hide the sun. If the boiler had a considerable capacity for heat, a series of such clouds might prevent getting full steam pressure at all on a day when the sun shone clearly one-half the time. But when the "flash boiler" is properly designed, full steam pressure comes on within 5 minutes after the sun emerges from such a cloud. This design involves the automatic regulation of the water supply, to be completely turned to steam as fast as supplied while the sun shines, and to be completely cut off when the sun is obscured. This requires a pump able to force water in against full steam pressure, and so regulated by the temperature of the boiler that the water flow ceases when the boiler cools, and reaches a maximum when the boiler temperature reaches the point for the desired pressure of steam.

SHUMAN ABSORBER, MEADI, 1913.



DIAPHRAGM PUMP.

DR. ABBOT'S SOLAR FLASH BOILER.

I accomplish these objects by employing a diaphragm pump, whose stroke is governed from zero to maximum displacement by a rotating cam of regularly increasing throw, operating through a pitman upon the pump. The cam is driven from the 60-cycle motor, above mentioned, and is mounted on a longitudinally displaceable carriage. The position of the carriage, and hence the throw of the cam, is governed by the differential heat expansion between the boiler tube and a tape of the non-expansible alloy, invar, attached thereto.

The water is forced through a small tube centrally to the lower end of the boiler tube, where it is guided by a spreader tube into a thin sheet bathing the inner wall of the boiler tube. The water bursts immediately into steam, which flows out to the engine through connections from the upper end of the boiler tube. A maze of heat-conducting copper vanes extends throughout the upper part of the boiler tube, so that only dry steam can escape therefrom. In large solar power installations, no doubt it would be desirable to use auxiliary superheaters.

The efficiency of such a device is a matter of critical interest for the future of solar power. It may be estimated as follows:

	Per cent
Mirror reflection	82
Sheath transmission	85
Boiler absorption	95
Heat not wasted	90
Boiler efficiency $0.82 \times 0.85 \times 0.95 \times 0.90 =$	60
Thermodynamic factor (as above)	36
Assumed mechanical efficiency of engine	75
Overall efficiency of conversion $0.60 \times 0.36 \times 0.75 =$	16.2

Recalling, as stated above, that the average receipt of solar energy throughout cloudless days in a favorable region corresponds to 1.15 Hp. per square yard of surface normal to the beam, we conclude that it will require a mirror of not less than 5.4 square yards, or 48.6 square feet, surface per horsepower under the most favorable of circumstances. Such a miror might well be 10 by 5 feet in projection. When we consider wind resistance and other limitations, including especially the glass tubing of the evacuated sheath, it seems difficult to suppose that units of more than 5 Hp. (area of mirror projection 12½ by 20 feet) would be found desirable.

Such units could be assembled in groups of thirty, occupying a ground area 150 feet, east-west, by 250 feet, north-south, without undue mutual shading, so as to give a maximum of 150 Hp. per group. Such a group of machines could be mechanically operated in common as regards rotation of mirrors and pumping of feed water. They could also deliver steam to a common superheater for use.

It is estimated that the United States uses the equivalent of approximately 10,000,000,000,000 Hp.-hours of power annually for light, heat, transportation, and manufacturing. Assuming, as above, 37,500 square feet of space required for 150 Hp. from the solar source, there would be required 30,000 square miles of territory to supply this entire requirement, assuming only 8 hours' sunshine per day of the average solar intensity stated above, namely 1.35 calories per square centimeter per minute. The State of New Mexico alone has approximately four times this area.

Cost and Other Considerations.

The cost of solar power is difficult to estimate. It depends on the quantity used. With large installations, care and upkeep would become nearly negligible, so that, with a 10 per cent return on investment, the cost of power at the plant might be estimated as less than ⅓ cent per Hp.-hour.

There remains to consider the serious drawback that direct solar power is unavailable at night. For certain purposes, as irrigation, this is not a serious objection.

However, since writing the above I have thought that the means shown in U. S. Patent 2,247,830, of July 1, 1940, could be expanded to include a strong insulated reservoir of water. Solar heating would be conveyed to the water, by gravity circulation through a coil immersed therein, from a black high-boiling liquid filling a vacuum-sheathed glass focus tube. In this way all the expense of the flash boiler would be eliminated, all moments of solar heating would be utilized, the water in the reservoir would be maintained in a superheated state night and day, and superheated steam would issue to the engine on opening a cock.

BOOK REVIEWS.

PRACTICAL MARINE DIESEL ENGINEERING—FOURTH EDITION. By Louis R. Ford. Simmons-Boardman Publishing Corporation, 30 Church Street, New York, N. Y. March 1943. Price $6.00.

Reviewed by Lt. Comdr. R. Baggaley, U.S.N.R.

Mr. Ford, a noted editor and writer who also carries a chief engineer's ticket, has described the construction, operation and repair of all sizes of marine Diesel engines as well as the machinery arrangements, drives, and auxiliaries used on various sizes of ships and tugs. Special attention has been given to the standardized ships of the Maritime Commission, as being indicative of future trends.

The book starts with the theory of the Diesel engine, presents the various types of engine construction used by the principal engine builders, shows the installation of engines, drives, and auxiliaries in ships and the features of each layout, and then goes into Diesel engine operation, lubrication, adjustment and repair. The characteristics and selection of fuel oil is covered.

This fourth edition contains new chapters describing the operating principles and the maintenance of electrical equipment, steering gears and deck machinery. Up to date information is provided on the requirements for motorship engineers' licenses and on the type of question appearing in the examinations.

All information is clearly presented with 322 illustrations. This is a valuable book for anyone having to do with motorships and particularly for prospective or licensed operating engineers.

QUESTIONS AND ANSWERS FOR MARINE ENGINEERS. Book III—Auxiliaries. Book V—Powering, Fuel Economy, Propulsion, Propellers, and Shafting.

MARINE ENGINEERING AND SHIPPING REVIEW. PUBLISHED BY SIMMONS-BOARDMAN PUBLISHING CORPORATION, NEW YORK. COMPILED BY CAPT. H. C. DINGER, U.S.N. (Ret.).

These two small paper-bound volumes of 139 and 97 pages, respectively, are presented in question-and-answer form for operating personnel.

COMBUSTION CHAMBER DESIGN FOR OIL ENGINES. BY PAUL BELYAVIN. PUBLISHED 1937 BY THE SHERWOOD PRESS, CLEVELAND, OHIO. 87 PAGES. COST $1.50.

REVIEWED BY LT. COMDR. A. D. MARKS, U.S.N. (RET.).

1. The subject matter of this book covers a short historical review of the development of Diesel and semi-Diesel engine mechanical injection combustion chambers wherein are illustrated and described both open and pre-combustion type chambers as well as various practical and theoretical considerations of combustion chamber design, presented in an elementary and easy-to-follow manner.

2. Four rules are set forth for efficient combustion of fuel and they are as follows:

a. "Get all the air available in the cylinder concentrated in one space as compact as possible, and of a shape suitable for distribution of jets radiating from one point.

b. Get all fuel jets, and as few in number as possible, evenly distributed over the combustion space, radiating from one point in the combustion space so as to be in a favorable relative position to the flow of air during compression stroke.

c. Take care that the combustion space is so shaped that a definite stream of air preferably of moderate velocity is produced in it during the end of compression stroke.

d. Avoid narrow or flat combustion chamber which would cause the fuel jet to graze the sides."

3. The text also covers the following topics: Heat Losses During Combustion, Efficiency of Fuel Injection, Combustion Chamber Efficiency, and Influence of Fuel Oil on Smoothness of Combustion.

4. Not enough data is contained on existing types of combustion chambers, there being only a few illustrations of modern types, and therefore the book is considered to be somewhat outmoded.

OTHER BOOKS RECEIVED.

WHITE ENSIGNS. By Taffrail (Captain Taprell Darling, D.S.O., R.N.). Published by G. P. Putnam's Sons, New York, $2.50.

AYE, AYE, SIR. By R. Osborn. Published by Coward McCann, Inc. 2 West 45th St., New York. $1.00.

OBITUARY.

REAR ADMIRAL JOHN GODWIN TAWRESEY, (CC), U. S. NAVY, RETIRED.

With the death, on February 17, 1943, of Rear Admiral John Godwin Tawresey, (CC), U. S. Navy, retired, the Society lost a member of very long standing. Admiral Tawresey joined the Society in the days before the records were established in good form, so his membership ante-dates 1909. He died at Jeanes Hospital in Philadelphia at the age of 81.

Admiral Tawresey was born in Odessa, Del., graduated from the Wilmington (Del.) High School and was appointed a cadet engineer at the U. S. Naval Academy in 1881. In 1885 he graduated as a naval cadet. He served on the Asiatic Station from 1885 to 1887 and as an ensign on the North Atlantic Station from 1888 to 1891. In 1891 he transferred to the construction corps of the Navy and in 1893 he graduated in naval architecture from the Royal Naval College, Greenwich, England.

He performed various tours of duty as assistant naval constructor and naval constructor at navy yards and private plants, including the Navy Yards at Brooklyn, N. Y., Portsmouth, N. H., and Philadelphia, Pa., and the Union Iron Works, San Francisco, Calif., Cramps Shipyard, Philadelphia, Pa., and the New York Shipbuilding Corporation, Camden, N. J.

He was on duty at the Philadelphia Navy Yard with the rank of captain in 1917, and in 1918 he was transferred to the Board of Inspection and Survey, Navy Department, Washington, D. C., where he served until his promotion to rear admiral in 1925. From then until his retirement for age in 1926, he served in the Bureau of Construction and Repair.

After his retirement he served with the United States Shipping Board. He was a delegate to the International Conference on the Safety of Life at Sea in London in 1929 and to the Interna-

tional Conference on load lines in London in 1930. He was intensely interested in the safety of ships and devoted untiring energy to it. As late as November, 1942, in spite of illness, he delivered a paper on the subject before the meeting of naval architects in New York.

In addition to the American Society of Naval Engineers, Admiral Tawresey was a member of the Institution of Naval Architects (England), a founder member of the Society of Naval Architects and Marine Engineers, a member of the Northeast Coast Institution of Engineers and Shipbuilders (England), the Franklin Institute of Philadelphia, the Naval Institute, the Army and Navy Club of Washington, D. C., and the Engineers Club of Philadelphia, Pa.

In 1893 Admiral Tawresey married Edith Jane Haken of Bury St. Edmunds, England, who died in 1940. He is survived by two daughters, Mrs. Alexander Whitney of Catonsville, Md., and Mrs. John S. Milne, Jr., of Philadelphia, and four sons, Captain A. P. H. Tawresey, U. S. Navy of Washington, D. C., John S. Tawresey of Jenkintown, Pa., and Harold R. Tawresey and Barrett G. Tawresey of Philadelphia, Pa.

ASSOCIATION NOTES.

MEMBERSHIP.

The following new members have been received since the publication of the February, 1943, JOURNAL.

NAVAL.

Adams, William P., Lieut., U. S. N. R., 535 Washington Ave., Bethlehem, Pa.

Anderson, Richard, Ensign, U. S. N.

Atkinson, William, Ensign, U. S. N. R.

Ballou, William R., 2 Linden St., Bath, Maine.

Bingham, Arlie C., Machinist, U. S. N.

Blinn, Paul Frazer, Lieut. Commander, U. S. N. R., Care Blinn's Cafe, 169 Market St., San Francisco, Calif.

Culberth, Robert R., Commander, U. S. N. R., Head Engineering Dept., Massachusetts Maritime Academy, Hyanis, Mass.

Curzon, J. A., Lieut., U. S. N. (Ret.).

Darrow, John B., Lieut., U. S. N. R., Yellow Creek Road, RD 7, Akron, Ohio.

Davenport, Gordon H., Ensign, U. S. N., 1827 Marin Avenue, Berkeley, Calif.

Ellis, James Franklin, Jr., Lieut., U. S. N., M. I. T. Graduate House, Cambridge, Mass.

Fleming, William J., Ensign, U. S. C. G., C. G. Inspector, Oxford Boat Works, Oxford, Md.

Grieshaber, George P., Ensign, U. S. N. R., 912 Chestnut Street, Union, N. J.

Hange, James F., Lieut. Commander, U. S. N. R., care Savannah Machine and Foundry Co., Shipbuilding Div., Savannah, Ga.

Hogan, John Thomas, Ensign, U. S. N. R., 185 Martin Avenue, Palo Alto, Calif.

Jones, W. T., Commander, U. S. N., U. S. Naval Drydocks, Hunters Point, San Francisco, Calif.

Lane, Charles A., Jr., U. S. N. R., Radio Laboratory, Navy Yard, Mare Island, Calif.

McChesney, Irvin G., Lieut., U. S. N., care Asst. Inspector of Naval Material, Babcock & Wilcox Co., Barberton, Ohio.

Maddox, Adolph, Lieut. Commander, U. S. N. R.

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Noonan, John D., Lieut. Commander, U. S. N. R., 12 Chesterfield Road, East Milton, Mass.

Plascjak, A. M., Electrician, U. S. N.

Rnouf, Rolfe, Machinist, U. S. N. R., Planning Division, Navy Yard, Boston, Mass.

Rice, Robert E., Ensign, U. S. N.

Smith, Franklin Bernard, Lieut., U. S. N. R.

Sutton, Joseph Randolph, Ensign, U. S. N.

Thomas, J. H., Ensign, U. S. N. R., U. S. N. R. Midshipmen's School, Notre Dame, Ill.

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Bermingham, Michael A., Hydraulic Engineering Inspector, 2825 Park Avenue, Minneapolis, Minn.

Ednie, James F., Chief Metallurgist, Duquesne Smelting Corp., 50 33d Street, Pittsburgh, Pa.

Lehecka, Frank H., Sales Engineer, Carnegie-Illinois Steel Corporation. Mail, 130 Prospect Street, East Orange, N. J.

Peyton, Jesse Arnold, Asst. Chief Draftsman, Alabama Drydock & Shipbuilding Co., Mobile, Ala. Mail, P. O. Box 1456, Fairhope, Ala.

Waller, C. Richard, Vice President and Chief Engineer, De-Laval Steam Turbine Co., Trenton, N. J.

Warren, Glenn B., Design Engineer, Turbine Engineering Dept., General Electric Co., Schenectady, N. Y.

ASSOCIATE.

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Gilbert, George H., Box 18, Navy 121, care Fleet P. O., New York N. Y.

Gorski, Stanley J., Inspector, Navy Dept., Milwaukee, Wis. Mail, 1711 South 4th Street, Milwaukee, Wis.

Hoopes, William U., Captain C. E., U. S. A., 603rd Engineers, Fort George G. Meade, Md.

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Morris, Wilson G., Inside and Outside Engineer, Ordnance Dept., Seattle-Tacoma Shipbuilding Corp., Seattle, Wash. Mail, 4127 Phinney Street, Seattle, Wash.

Moskway, John M., Marine Engineer, Navy Yard, Philadelphia, Pa. Mail, 114 South 40th St., Philadelphia, Pa.

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Pasback, A. R., Associate Principal Inspector of Ship Construction, Machinery, care Asst. Supervisor of Shipbuilding, U. S. N., Seneca, Ill.

Preston, Irving S., Steel Requirements Engineer, U. S. Steel Corporation, Pittsburgh, Pa. Mail, 4712 Doyle Road, Pittsburgh (10), Pa.

Rebbeck, L. E., Commander, Royal British Navy, British Embassy, Washington, D. C.

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